HEAT STRESS IN DAIRY CATTLE

Physiological Responses and Variations
in
Milk Composition and Equilibrium

by
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Except as stated therein, this thesis contains no material which has been accepted for the award of any other degree or diploma in any University, and to the best of my knowledge and belief, contains no copy or paraphrase of material previously published or written by another person, except where due reference is made in the text of the thesis.

Hywel V. Rees

(Hywel V. Rees)

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1. SUMMARY

Dairy cattle were exposed to air temperatures from comfort to heat stress levels within the range 70°F to 105°F in which relative humidity changed from 71.0 ± 2.0 percent at 70°F to 36.0 ± 1.0 percent at 105°F.

The following reactions were studied under conditions of constant and alternating day/night temperatures in which different feed treatments were used (dry feeds, balanced and unbalanced for milk production) :- rectal temperature; respiration rate; pulse rate; rumenal movement; animal behaviour; milk production and composition (solids-not-fat and butterfat content); inherent acidity and freezing point of milk; water and feed consumption; body weight.

Temperature increase above an apparent threshold (85°F) resulted in rectal temperature increase and severe disturbance in respiratory and cardiac function. The respiration rate increased prior to body temperature and both showed a significant correlation with air temperature. The pulse rate was initially stimulated but declined to minimum rates when body fever was maximum.

The cycle of rumination was not influenced by ambient temperature.

Distress and nervous tension was evident at temperatures greater than 95°F but sweat-gland activity was strictly limited. Changes in behaviour (restlessness, panting, tongue protrusion, frequent visits to water, salivation, sliming of nostrils and change in faecal texture) were most apparent in cows which experienced greater body temperature increase.

During active heat dissipation, important differences between cows were recorded in the relative emphasis placed on the different physiological responses involved in maintenance of homeostasis.

Milk composition and equilibrium changes were related to increase in rectal temperature. There were decreases in solids-not-fat, acidity and the freezing point depression which were unrelated to feed treatment. Changes in butterfat were extremely variable and did not conform to a common pattern.

The degree of animal response was influenced by the intensity and duration of heat stress. Constant heat stress conditions effected a progressive decrease in milk yield and production of fatty and non-fatty solids. Animals under heat stress for shorter periods (alternating day/night temperatures) did not show this trend.

In each Trial, the cow with the higher milk production level was least able to cope with a hot environment as shown by greater body temperature increase, more intense depression of solids-not-fat and acidity and higher elevation of the freezing point. This response was independent of feed treatment and suggested a probable relationship to a higher heat increment resulting from greater mammary gland metabolism and the difficulty of dissipating extra heat.

Decline of feed intake paralleled and reflected decline in milk production and was associated with body weight loss when heat stress effected a significant increase in body temperature. (3° to $4^{\circ}F$ rise above normal). Conditions in which feed intake and milk production remained relatively constant were associated with lower body temperatures and body weight gains.

Body weight decreased under constant temperature exposure and increased under alternating day/night temperatures. In each case the balanced diet minimised weight loss and increased weight gain.

Water consumption greatly increased with air temperature increase but in one cow was reduced to a level below maximum intake when there was a drastic decrease in milk production and feed intake.

The chance occurrence of "natural" body fever in the field permitted observation of concurrent changes in milk and body temperature. Changes in milk production, composition, acid-base balance and osmotic pressure were similar to those associated with increase in body temperature induced by ambient air temperature increase. The pulse rate but not the respiration rate was similarly affected.

Improved animal performance at higher temperatures within the comfort zone (indicated by stability of rectal temperature) was considered to be due to greater efficiency of feed utilisation and the lower energy requirement for body heat maintenance and general metabolism. This trend was independent of the effect of feed treatment.

Marked milk changes occurred during controlled conversion from field to trial feeding of the unbalanced ration which were similar to those effected under heat stress conditions. This suggested that in the field environment, the effect of change in the qualitative character of seasonal feed could either be supplementary or complementary to that of the direct effect of temperature on the dairy cow.

The contribution by solar radiation and humidity to the heat load placed on the lactating cow is discussed. The evidence suggested that in the field, a much lower shade-temperature than that established in this study would initiate and sustain similar changes in milk composition and equilibrium.

The changes recorded in milk when cows were in heat stress, may be related to changes in blood composition and acid-base balance.

2. INTRODUCTION

Field studies (Rees; 1949 : 1952) indicated that seasonal change in the thermal and nutritional environment was related to milk composition change and osmotic disturbance in milk. These in turn were intimately linked with the effect of stage of lactation and period of gestation.

The particular behaviour of mid-lactation milk (bulk and herd unit) during mid-late summer featured depression of Solids-not-Fat and Acidity levels and elevation of the Freezing Point. These effects intensified with increase in severity of the summer environment.

Under practical conditions of dairy-herd management, studies on physico-chemical change in milk are subject to and so often confounded by the uncontrolled but positive influence of climate, operating directly on the dairy cow or indirectly through such channels as seasonal feed change.

The individual effect of climatic components such as temperature, air-humidity and movement, solar radiation, &c., cannot be assessed.

In recent years, considerable attention has been focussed on the effect of climate, particularly temperature, on dairy cattle behaviour, but limited information is available directly relating thermal stress in dairy cattle to milk composition and equilibrium change.

A feature of current and fundamental studies is the increased use of the psychrometric room, in which climatic components and experimental variables may be standardised and/or eliminated.

Such procedure was utilised in this work, and the effects of exposure to constant and alternating day/night air-temperatures, were investigated.

As pregnancy also influences body-temperature, (Findlay; 1950), non-pregnant cows were used during exposure to constant air-temperatures. The oestrus cycle was eliminated during exposure to alternating day/night air-temperatures, for reasons explained later in the text.

Diet and animal management were standardised and cows were subjected to trial conditions only when physico-chemical tests in the field indicated strong stabilisation of values, thus ensuring limitation of the significant post-parturitional influence. The relatively short duration of thermal exposure and the method adopted for cow submission, reduced the effect of stage of lactation to a uniform and practical minimum.

The investigation was primarily concerned with obtaining information on the fundamental effect of thermal stress and associated physiological disturbances in dairy cattle, on milk composition and equilibrium, so that in field studies the influence of high summer temperature may be more completely understood.

3. REVIEW OF THE LITERATURE.

THE DIRECT EFFECTS OF HIGH AIR TEMPERATURE, HUMIDITY AND SOLAR RADIATION ON THE HEALTH AND PRODUCTIVITY OF TEMPERATE BREEDS OF DAIRY CATTLE.

The direct effects of climate on the health and productivity of temperate breeds of dairy cattle has received increased attention in recent years. This review deals primarily with studies on animal response and performance, under field and psychrometric room conditions, to those climatic components (high air-temperature, solar radiation and humidity) which singly or in combination induce heat stress. It is prefaced by reference to the principal methods of heat production and heat loss and to the mechanism of heat regulation in cattle.

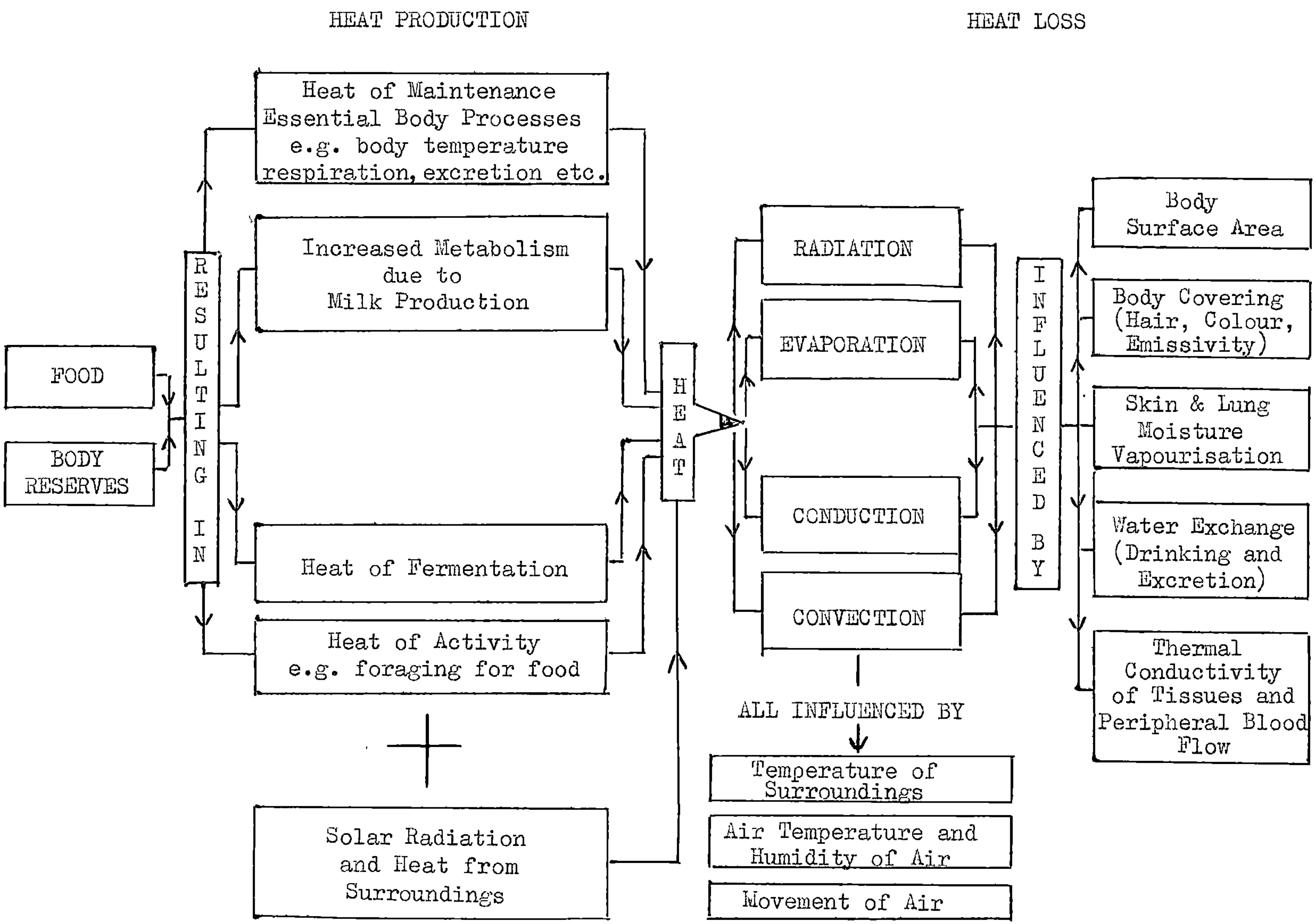
Methods of Heat Production and Heat Loss

It is considered that normal warm-blooded animals maintain a constant body temperature with narrow limits of variation within the zone of thermoneutrality. The literature gives a rather wide range for normal body temperature for dairy cattle. Freeborn et alia (1934) and Brody (1945) give the normal body temperature of European type cattle as 101.0°F; Dukes (1947) gives 100.4° to 102.8°F with a mean of 101.5°F as normal. Regan and Richardson (1938) consider 101.0° to 102.0°F as normal while Gaalaas (1945) recorded 101.1° ± 0.5°F within the air temperature range of 50° to 60°F.

Homeothermy is attained by maintaining a balance between heat production (thermogenesis), heat absorption and heat loss (thermolysis). The following diagram from Findlay (1950) shows the principal methods by which heat is produced, gained and lost in cattle.

The amount of heat generated is so great that emission rather than heat production or conservation is the main problem confronting lactating dairy cattle.

THE PRINCIPAL METHODS OF HEAT PRODUCTION, GAIN AND LOSS IN CATTLE (FROM FINDLAY, 1950)



Hancock (1954) lists those reactions which are important in cattle in maintaining a stable body temperature.

To Counteract Falling Body Temperature	To Counteract Rising Body Temperature
Seeking of shelter from wind and rain	Seeking of shade
Huddled position	Relaxed position
Vasoconstriction	Vasodilation
Muscular activity by:- Tensing of muscles; Exercise; Shivering	Avoidance of unnecessary exercise
Increased feed intake	Decreased feed intake
Increase in hair thickness and length	Decrease in hair thickness and length
Increase in sub-cutaneous fat	Increased respiration rate
	Vaporization from respiratory tract and skin

The problem of heat emission is greatly accentuated in European breeds of cattle when air temperature exceeds the critical level of 70°F and when, despite a very marked increase in the respiration rate, body temperature begins to exceed the normal. The critical temperature of cattle evolved in the tropics (Zebu) is much higher (90°F) and their greater heat tolerance is thought to be due to such factors as:- lower feed intake; lower productivity; larger surface area to body weight ratio; more active sweat glands and lower basal metabolism (Findlay 1950).

Mechanism of Heat Regulation

Dukes (1947) and Best and Taylor (1950) state that the factors involved in heat conservation and heat loss are intimately inter-related and are dependent upon the function of vital temperature-regulating nervous centres, differentially located in the hypothalamic portion of the forebrain. These govern the activities of the autonomic or involuntary nervous system which in turn exercises the important function of maintaining the constancy of the fluid environment of body cells. Regulation of its composition, temperature, quantity and distribution is effected through action upon the circulatory, respiratory, digestive, excretory and glandular organs.

These extremely sensitive heat centres are activated by the temperature of the blood or by nervous reflexes and impulses from nerve-endings located at or near the body surface (Lee and Phillips 1948).

Brody (1945:1948) differentiates between chemical and physical regulation of body temperature, the former operating mainly when air temperature falls below the lower critical limit for the zone of thermoneutrality. Within and above this zone, regulation is mostly physical.

I EFFECTS ON PHYSIOLOGICAL RESPONSES

(a) Body Temperature and Respiration Rate

Studies in environmental physiology under field and psychrometric room conditions clearly indicate that air temperature increase above the zone of thermoneutrality increases body temperature and respiration rate to a marked degree and that increase in humidity at high temperatures produces the same effect.

Lee and Phillips (1948); Findlay (1950); McDowell (1956) and Yeck (1959) have presented reviews of environmental research in this field.

The literature strongly supports the existence of a critical hyper-pyrexial air temperature in the vicinity of 85°F above which body temperature and respiration rate sharply increase and inefficient thermolysis is initiated. This critical thermal level has been specifically indicated by Hall and Brody (1933); Regan and Richardson (1938); Rhoad (1938:1940:1944); Gaalaas (1945); Seath and Miller (1946:1948); Riek and Lee (1948) and Kibler and Brody (1949:1950:1951).

(i) Data from Psychrometric Room Studies

Regan and Richardson (1938) exposed Holstein, Jersey and Guernsey lactating cows to progressive changes in environmental temperature (40 to 100°F) for periods of 5 - 10 days; humidity (60 percent relative humidity) and air movement (50 ft. per min.) conditions were constant.
At temperatures 40 to 60°F, body temperature remained constant at 101.0°F but the respiration rate increased from 12 to 28. Further temperature increase from 70 to 100°F effected progressive and rapid increases in body temperature (101.3 to 105.1°F) and the respiration rate (42 to 124 respirations per min.).

Riek and Lee (1948) investigated the effect of varying dry-bulb temperature (85 to 110°F) at constant absolute humidity (12 gr./cu. ft.) and varying absolute humidity (6 to 16 gr./cu. ft.) at constant dry-bulb temperature (105°F) with four grade Jersey cows in lactation. Air-movement was relatively constant at a velocity of about 60 ft./min. and exposure was for 7 hr. or until the rectal temperature reached 107°F.
Mean rectal temperatures under atmospheric conditions were 101.17 ± 0.67°F and rose to higher values with less ready establishment of equilibrium, the hotter the condition, but exceeded 107°F only in the hottest atmosphere (dry-bulb temperature 110°F; absolute humidity 16 gr./cu. ft.). The respiration rate was similarly and markedly affected. The mean ante-room respiratory rate was 25.4 ± 6.1 respirations per minute and rose to about 160 respirations per min. at the higher combinations of temperature and humidity. The highest average rate was 200 per min. and the respiratory minute volume rose less than the rate, so that tidal volume was reduced.

In both cases humidity had a marked effect as well as temperature, an increment of 0.4 gr./cu. ft. (approx. 4 percent) in humidity having the same effect as 1°F rise in air temperature.

Kibler and Brody (1949:1950:1951) observed rapid rectal temperature increase in Holstein, Jersey and Brown Swiss cows, with increase in air temperature and humidity.
Rectal temperatures remained normal during exposure to temperatures of 5 to 40°F and 40 to 75°F, but rapidly increased above 75°F, attaining levels of 102°F and 108°F at air temperatures of 80°F and 105°F respectively. Relative humidity varied within the range 55 to 70 percent and the maximum duration of exposure at 105°F was 9 hr.
High humidity accentuated rectal temperature increase when air temperature exceeded 75°F and relative-humidity decrease from 81 to 60 percent at 95°F decreased rectal temperature by 2°F.

Bartlett (1935) recorded that respiration rates increased with increases in temperature ranging from 20 - 24 per min. at 45 - 57°F to 36 - 50 per min. at 75 - 87°F.

Kleiber and Regan (1935) noted that, with increasing environmental temperature, humidity being controlled at 50 percent saturation, the respiratory rate followed the van't Hoff law, doubling for each rise of 10°C in the air temperature.
Studies by Rhoad (1936); Regan and Richardson (1938); Brody (1945) and Blaxter and Price (1945) confirmed this observation.

Available information on the specific effect of radiation in a constant air temperature environment is rather limited.

Brody et alia (1954) investigated the thermal effects of radiation intensity (light) in Holstein and Jersey cows. Exposure to a radiation level of 180 B.t.u./hr. ft.^{2} by incandescent and fluorescent lamps and simulating solar radiation in the psychro-energetic laboratory, accentuated the deleterious effects of high temperatures on rectal temperature increase.

Kibler and Brody (1954) caused rectal temperatures of Friesian cows in lactation to increase about 3°F in an 80°F environment, by increasing radiation intensity from 5 to 180 B.t.u./hr. ft.^{2}.

(ii) Data from Field Investigations

Gaalaas (1945) presented results of a study of the bodily reactions of Jersey cattle to changes in atmospheric temperature (33° to 95°F) as measured by body temperature and respirations per min. (3298 individual recordings).
A definite relationship existed between body temperature and air temperature. The average body temperature ranged from 101.0°F at an average air temperature of 50°F, to 103.2°F at an average air temperature of 95°F, with a correlation coefficient of $\pm$ 0.57 $\pm$ 0.0079.

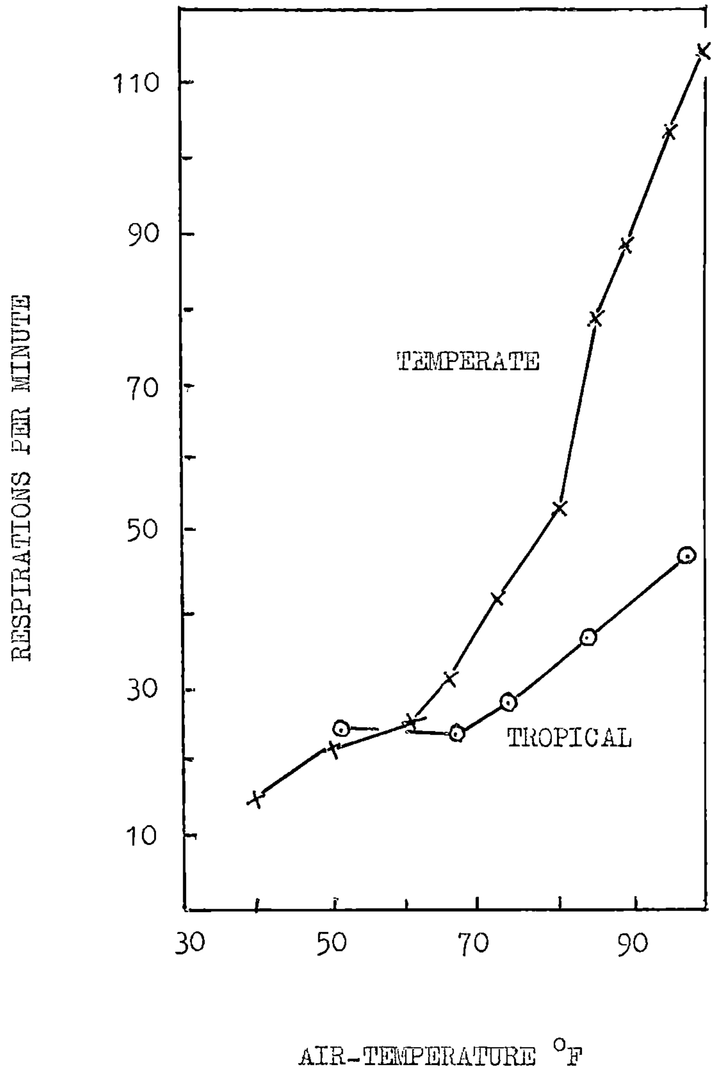
A similar strong correlation existed between respiration rate and air temperature, the average ranging from 20 per min. at 50°F, to 90 per min. at 95°F, with a correlation coefficient of $\pm$ 0.77 $\pm$ 0.0048. There was a wide difference between individual cows in the degree of body reaction to high temperatures and exposing cows to the sun caused an average rise of 0.7°F in body temperature compared to shade conditions at the same high air temperatures.

Rhoad (1938:1940) established a similar relationship of air temperature to the respiration rate of temperate, tropical and cross-breeds of beef cattle under shade (68 to 80°F) and non-shade (80 to 102°F) conditions. The ability to resist increase in body temperature and respiration rate was least with the temperate breed and related to the amount of tropical blood within each genetic type.

Seath and Miller (1946) studied the effects of high temperatures and humidities in temperate cattle (77 Holsteins and 43 Jersey cows) over a period of two years and recorded that humidity played a minor role compared with air temperature in causing increases in rectal temperature and respiration rate.
They concluded that a 1°F rise in air temperature was responsible for from 13 to 15 times as great an effect on the body temperature as an increase in 1 percent in the relative humidity at the same air temperature. Partial correlations between air temperature and body temperature (humidity held constant) were 0.674 and 0.534.
Air temperatures and respiration rate were highly correlated (the latter increased from 22 to 129 per min. with increases in temperature from 65 to 93°F and humidity from 27 to 91 percent R.H.) and a change in air temperature of 1°F had from 41 to 43 times as much effect on the respiration rate as a 1 percent change in relative humidity.
On a partial correlation basis (air temperature held constant) an increase in humidity slightly lowered respiration rate. The "r" values were -0.06 and -0.02.

The following composite graph, compiled by Findlay (1950) illustrates the difference between temperate and tropical breeds of cattle, in the behaviour of their respiratory rate with rising air temperature.

Graph showing the difference between temperate and tropical breeds of cattle in the behaviour of their respiratory rate with rising air-temperature.



Graph compiled by Findlay, (1950); data for each point were abstracted from the work of Gaalaas, (1945), Regan and Richardson, (1938), Rhoad, (1936; 1938; 1940), and Bonsma, Scholtz and Badenhorst, (1940).

Bianca (1962) investigated the relative importance of a high wet-bulb temperature compared with a high dry-bulb temperature in causing heat stress. Findings, in terms of rectal temperature response, indicated that the effect of the former was about twice as greater as that of the latter.

The level of milk production has been shown to influence the degree of response of cows to hot conditions: studies by Ittner et alia (1954) and Johnston et alia (1954) indicated that the highest producing cows tend to have the highest body temperatures and respiration rates on hot days.
The contribution to the heat load due to milk production is considerable. Brody et alia (1948) estimated that each 1 lb. of fat corrected milk (F.C.M.) produced, increases metabolic heat production by approximately 10 kilo calories of heat per hour. A 1000 lb. cow, with a resting heat production of 500 kilo calories per hour, producing 50 lb. of F.C.M. per day, would have a total metabolic heat load of 1000 kilo calories or double the resting heat load. Thus the higher the level of milk production, the greater is the heat load imposed on the cow.

Direct exposure to solar radiation greatly intensifies the heat load and reduces the potential for radiation loss.

Kelley and Ittner (1948) found that shading an animal from the sun reduces the radiant heat load on it, by 30 to 50 percent.

Bond and Ittner (1954) showed that the radiant heat load may be reduced from 244 to 167 B.t.u./hr. ft.^{2} of animal surface by shade alone, equivalent to reducing mean radiant temperature * from 153°F to 98°F. Thus a net radiant gain to the animal of about 70 B.t.u./hr. ft.^{2} could actually be reduced to a net loss by shading.

Shrode, Williams and Harris and their colleagues (1960) published a series of studies in which they investigated the influence of summer weather factors (solar radiation, temperature, vapour pressure and wind velocity) on physiological and production responses of lactating Holstein and Jersey dairy cattle.
They concluded that air temperature variations were the predominant cause of variations in body temperature, respiration and pulse rates. For shaded animals, increases in solar radiation caused no appreciable direct influence upon these physiological responses. For non-shaded animals it did have a direct effect on body temperature when air temperatures were close to the range of thermoneutrality (below 90°F) but little effect at higher air temperatures (above 90°F).

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* Bond and Ittner define mean radiant temperature of an environment as the temperature of a uniform black enclosure with which an object would exchange the same amount of energy as in the actual environment.

Exposure to direct solar radiation had greater effect than any other weather influence on the respiration rate, but did not cause any appreciable change in milk production.

(b) Pulse Rate

The pulse rate of dairy cattle in normal environments varies between 60 to 70 beats per min. (Dukes 1947). Average rates for temperate cattle of various breeds and ages by Fuller (1928) and Alfredson and Sykes (1942) confirm this range, with however wide individual variations.

Findlay (1950) stresses that in any attempt to assess the effect of climatic components on pulse rate, such factors as the nervous state of the animal, its state of nutrition and the stages of gestation and lactation, which do affect the heart rate, must be considered.

Regan and Richardson (1938) observed a decline from 72 beats per min. at 50°F to 57 beats per min. at 95°F.

Brody (1945) recorded similar decreases and suggested that if temperate cattle were ill-endowed with functional sweat glands, blood would be drawn from the periphery under conditions of external heat stress and pulse rate would decline.

Riek and Lee (1948) concluded that the pulse rate was essentially unaffected by a rise in air temperature but tended to rise somewhat with absolute humidity increase.

Studies by Kleiber and Regan (1935); Regan and Freeborn (1936); Ritzman and Benedict (1938) and Seath and Miller (1946) indicated that increases in environmental temperature have no consistent effect or they have a tendency to cause it to decline. Viewing these studies collectively, Findlay (1950) stated that it might appear that increasing the blood flow and hence the thermal conductance through the superficial tissues, is not a factor of prime importance in thermolysis in cattle.

Ralston et alia (1940) observed a seasonal variation in the heart rate which declined in the hotter months.

Kelley and Rupel (1937) noted increase at low air temperatures, the increases being marked below 50°F.

Field studies by Bonsma and Pretorius (1943) on the effect of temperature and sunlight on the heart rate of European cattle in the tropics, indicated that under shade conditions, the pulse rate declined with air temperature increase, rates of 72 and 84 beats per min. at 80°F decreasing to 69 and 78 beats per min. at 88°F. Under similar conditions of exposure in the sun, pulse rate increased considerably, rates of 85 to 87 beats per min. at 85°F rising to 91 and 95 beats per min. at 92°F.

Kibler, Brody and Worstell (1949) recorded an initial increase within the temperature range 60 to 70°F. The rate declined rapidly above 70°F and with Jersey cattle continued to fall with temperature increase to 105°F. Holsteins exhibited this pulse rate decline only up to 95°F after which an increase was noted.

Lee and Phillips (1948) concluded that deductions as to cardiac output or general circulatory activity, cannot easily be drawn from the pattern of heart-rate behaviour, though in general an increased pulse rate denotes increased cardiac output.

The weight of evidence in the literature referred to, does indicate that when an increase in air temperature causes a change in the pulse rate, the result is a decrease.

(c) Thyroid Secretion Rate

Thyroxine is acknowledged to be essential for maintenance of normal basal metabolic rate and that the administration of the thyroid hormone increases milk yield and body temperature. Studies have shown that there is a relationship between temperature and thyroid activity.

Blincoe and Brody (1955) showed that low temperatures (17°F) increased thyroid activity 60 to 100 percent in Jersey and Brahman cows but showed no significant change in Holstein and Brown Swiss cattle. Air temperatures of about 95°F decreased the thyroid activity of all breeds by 30 to 65 percent. A daily temperature cycle of 10 to 40°F increased thyroid activity by 20 percent over the values of a cycle of 40 to 70°F and a cycle of 70 to 100°F decreased the activity about 30 percent below the 40 to 70°F cycle.

Johnson (1958) and Kamal et alia (1959) reported that normal levels of neuro-endocrine activity are depressed by a hot environment, resulting in reduction of the thyroid secretion rate.

Johnston (1958) recorded a 60 percent reduction in the estimated thyroid secretion rate (PBI levels) of lactating cows in the summer period.

Premachandra (1958) showed that thyroxine secretion rates were reduced threefold in summer and concluded that apparently an increasing warm environment may be a greater stimulus to a reduction in thyrotropic hormone secretion than would be an increasingly cold environment for increasing thyrotropic activity.

McDowell (1958) stated that changes in thyroid activity appear promising as evidence in evaluating responses to thermal stress.

II EFFECTS ON MILK PRODUCTION, COMPOSITION AND EQUILIBRIUM

(i) Data from Psychrometric Room Studies

Psychro-energetic laboratory studies by Ragsdale et alia (1948:1949:1950:1951) and the associated study by Worstell and Brody (1953) integrating the physiological data obtained on the effect of temperature on lactating cows, clearly indicated that rising temperature affected the production of European animals (Jersey, Holstein and Brown Swiss cows) profoundly above the level of 60°F and when respiration and moisture vapourization rates were suddenly accelerated and reached a maximum at 85°F.
Rectal temperature increase (initiated at 70°F) was followed by depression of feed consumption, milk production, pulse rate and heat production. Milk production and feed intake virtually stopped at 105°F but a temperature reduction to control levels (50° to 60°F) effected a return to normal. Butterfat percent increase above 85°F was associated with milk yield decline regardless of high temperature. The decline in pulse rate paralleled the decline in milk production, feed consumption and heat production.
Low heat tolerance of the temperate breeds appeared to be associated with low moisture vapourization (for heat dissipation) and high heat production per unit surface area. The cattle did not "sweat" in the sense that man sweats. Brown Swiss cows were more heat tolerant than Holsteins and equal to that of Jerseys.
Brahman (Indian) cows lagged behind the European by about 15°F in their rectal temperature increase, decline in milk production and other physiological reactions due to their 12 percent greater surface area per unit weight, lower heat production (lower productivity and lower basal metabolism) and to low initial levels of the physiological functions, providing a greater range for increase under heat stress. As air temperature approached 105°F, the distress in the Indian cows approached that of the European.

The study by Ragsdale et alia (1953) dealt with the effect of low and high relative humidities at high temperatures (75° to 100°F) on milk production.
The effect of humidity at 75°F was not significant; at 85°F the depression was greater at high than low humidity and the difference increased with air temperature increase. Under conditions of continuous exposure, milk production losses at 95°F and 45 percent relative humidity were equivalent to those experienced at 85°F and 95 percent relative humidity. Butterfat percentage tended to increase but the non-fatty solids showed little, if any, change.

Regan and Richardson (1938) studied the reactions of 6 pairs of cows (Holstein, Jersey and Guernsey) at variant temperature levels within the range 40° to 95°F.

The average milk yield decreased from 29 to 17 lb. per cow. Above 80°F, physical and chemical changes in milk were marked and trends definite. There were decreases in the concentration of solids-not-fat from 8.26 to 7.58 percent and of casein from 2.26 to 1.81 percent; butterfat declined from 4.2 to 3.9 percent at 85°F with subsequent increase to 4.3 percent at 95°F; a slight decrease was evident in the freezing point depression (0.536° to 0.525°C) and pH change (6.53 to 6.65) indicated a slight decline in the buffering capacity. The rennet coagulation time increased and the butterfat secreted at 95°F was lower in volatile acids and higher in unsaturated components.

Cobble and Herman (1951) and Richardson (1961) observed a significant decrease in milk yield and the solids-not-fat percent at a critical temperature range of 85° to 90°F.
The former workers did not observe important change in the freezing point depression during temperature increase from 40° to 105°F (there was a slight tendency to decrease) even though substantial changes occurred in the lactose and chloride contents. The first increase in chloride and decrease in lactose were recorded at 80° to 90°F and 95° to 105°F respectively.

Riek and Lee (1948) and Merilan and Bower (1957) investigated the effect of high temperature diurnal rhythms on milk composition change. The former workers utilised daily seven hour periods of exposure to dry-bulb temperatures from 85° to 110°F at high humidities and recorded a solids-not-fat increase of 0.69 percent and increase in the specific gravity of milk from 1.0318 to 1.0346; milk yield and butterfat percentage were unaffected.
The latter workers confirmed solids-not-fat increase but stressed that changes in milk composition occurred rather slowly and trends for any specific temperature cycle (diurnal temperatures of 70° to 100°F and 60° to 110° were utilised) were modified by the preceding cycle, unless a suitable adjustment period was interposed between the different temperature ranges.

Lee (1949) later showed that continuous exposure to 99.5°F caused a marked decline in milk production.

Bartlett (1935) compared the effects of two temperature ranges, 33° to 56°F and 47° to 87°F and for the higher range recorded a small non-significant decrease in milk yield and fat percentage. The percentage of solids-not-fat was significantly lower by 0.15 percent.

Kamal et alia (1961) studied the influence of temperature on the salt balance of milk, alternately exposing non-pregnant Holsteins to comfort temperature (65°F) and heat (80° to 90°F).

Milk yield, total phosphorus and magnesium were markedly depressed at high temperature. Salt balance showed a statistically significant decrease, indicating a smaller difference between concentration of anions (citrates + phosphates) and cations (calcium + magnesium) in heat than in cold. Average values for salt balance at the different temperature levels were:-

$$0.55 \text{ Mol. } \times 10^{-3}/100 \text{ m.l. at } 65^{\circ}\text{F}$$

$$0.29 \text{ Mol. } \times 10^{-3}/100 \text{ m.l. at } 80^{\circ}\text{F}$$

Heat caused no marked change in sodium and sodium potassium ratio. Potassium values were lower at the higher temperature but the difference was not significant. Only with cows in early lactation did citric acid and calcium content significantly change.

(ii) Data from Field Investigations

Most field studies on the effects of climate are related to a comparison of seasonal variation to seasonal temperature trends and the important effects of seasonal change in feed cannot be separated from the direct effects of temperature.

The co-operative study undertaken by the Departments of Agriculture of New Zealand and the Crown Colony of Fiji, viz. "The Direct Effect of Tropical Climate on the Performance (Growth and Production) of European-type Cattle" and reported on by Hancock and Payne (1955) and Payne and Hancock (1957), is of particular importance, as seasonal feed effects were entirely eliminated in the work. Eight sets of temperate-breed identical twin heifer calves were divided between Fiji and New Zealand and growth and production recorded to the end of their first lactation. Temperature and humidity differences between the two centres were:-

	1951		1952 (Jan-July)	
	Fiji	New Zealand	Fiji	New Zealand
Average maximum temperature (°F)	83.9	64.6	85.5	65.0
Average minimum temperature (°F)	68.2	44.1	70.0	45.2
Mean temperature (°F)	76.0	54.2	77.7	55.1
Average relative humidity (percent)	79.9	84.0	80.3	84.9
Average absolute humidity (grains moisture per lb. dry air)	116.5	56.6	123.7	57.9

Maximum temperatures in New Zealand barely exceeded minimum temperatures in Fiji; the relative humidity was approximately the same but the absolute humidity much higher in Fiji. The feeding procedure made it possible to feed foods of approximately the same origin at each centre at the same time. Final production records were presented for six sets of twins.

Average milk production was 44 percent higher in New Zealand, as was butterfat (56 percent) and solids-not-fat (19 percent). In the case of solids-not-fat the average difference (67.9 lb.) in production was not statistically significant as there was virtually no difference in the average percentage. Butterfat percentage was higher in New Zealand but the average difference not statistically significant. Average butterfat and solids-not-fat percentages were:-

	New Zealand	Fiji
Solids-not-fat	8.509	8.631
Butterfat	5.155	4.755

The average feed intake of the Fiji twins was lower, the average water consumption higher (approximately twice) and the average daily rectal temperature and respiration rate considerably greater, than those of their co-twins in New Zealand. The twins in Fiji did not respond in a uniform manner to the stress of a tropical climate. Hancock and Payne suggested the operation of a genotype-climate interaction, which indicated that individual European-type cattle differ in their reaction and suitability for tropical climates.

Rhoad (1935) observed that pure bred European dairy cattle fed on balanced rations in Brazil failed to give milk yields corresponding to those expected in a temperate climate.

Bonsma (1940:1948) recorded marked decline in milk production in temperate cattle in the tropics during severe hot spells and attributed this to non-effective conversion of the feed under the specific climatic conditions.

Rice (1949) noted that in Fiji, cows in the better producing herds, gave about 60 percent of the yield of cows in similar herds in New Zealand.

Ashton (1956) in his world survey of milk and butterfat recording, presented data showing the lower yields of cows in above-average herds in warm climates, compared with those in temperate climates.

Mahadevan (1957) studied variation of performance of five breeds of European cattle (Ayrshire, Friesian, Shorthorn, Red Poll and Jersey) in Ceylon.
From statistical examination of data, he concluded that differences in the extent of milk production variation between stock reared in tropical and those reared in temperate countries, were due to differences in husbandry rather than to any great inherent differences between tropical and temperate breeds.
In the Red Sindhi breed in Ceylon, the increase in milk yield from the first to the fourth lactation was only 6 percent compared with 19 to 32 percent for the European breeds, which are similar increases to those of European breeds in temperate countries.

Established seasonal trends in milk composition change are dissimilar in temperate countries of the Northern Hemisphere compared to those of the Southern Hemisphere (Rees 1949), but have in common, depression of solids-not-fat change to minimum values in the summer and minimum or sustained low butterfat values associated with temperature increase from spring to summer. Such seasonal features and basic differences with respect to the seasonal occurrence of maximum solids-not-fat and butterfat levels, are confirmed in the work of Hills (1892); Brooks (1895); Eccles (1909); Speir (1909); White and Judkins (1918); Richmond (1920); Ragsdale and Turner (1922); Tocher (1925); Weaver and Matthews (1928); Andrew (1928); Grigg (1929); Overman et alia (1929:1939); Baker and Cranfield (1933); Davies (1939); Overman (1945); Van Rensburg (1946:1947); Rees (1947:1949); Davis et alia (1947) and the extensive recordings for Food and Drugs Act and commercial samples published by Elsdon and Walker (1942).

The marked depression (lower than average and even below chemical standard) of solids-not-fat associated with spells of high temperatures and drought conditions in the Northern Hemisphere, is specifically referred to by Cranfield (1930); Nottbohm (1930); Houston and Hale (1932); Jacobson (1936) and Herman (1938).

Smit (1929) and Trambicus (1938) recorded the depressing influence of drought conditions in South Africa; Bakalor and Labuschagne (1959) the serious decline in bulk milk receival and depression of casein and butterfat to minimum percentages during a drought period in the semi-arid North-Western Cape Province and Labuschagne (1954) the seasonal variations in casein, calcium, phosphorus and chloride contents, with depression of levels in summer.

Rees (1949) reported in Tasmania that the average monthly solids-not-fat content (daily samples) was below the chemical standard in unselected market milk and in a bulk supply from 15 herds in a defined milk district under dry summer conditions (February). Differences between maximum (November) and minimum (February) average values were 0.67 percent in the unselected and 0.73 percent in the selected milk supply.

Nichols and Few (1950) recorded wide monthly variations in yield and composition from eight Queensland herds involving five temperate breeds. A serious decline in casein and butterfat percentages occurred during a low rainfall period and Nichols (1958) later observed that during a drought the average solids-not-fat and butterfat in the pasteurised milk supply of a large city, decreased respectively 0.6 percent (8.6 to 8.2) and 0.4 percent (3.9 to 3.5).

Brooks (1931) in a study of 409 lactation records over a period of 15 years, found close inverse correlation between temperature and butterfat percentage and observed that air temperature had a greater influence on the butterfat percentage, than did the stage of lactation.

Ragsdale and Brody (1922) recorded that the butterfat percentage decreased about 0.2 percent for each temperature rise of 10°F between the observed temperature limits (70° and 30°F).

Hays (1926) observed a decrease of only 0.079 percent for the same temperature increase within the range 24.5° to 85.5°F under field conditions but in controlled temperature trials recorded an average decrease of 0.189 percent for each 10°F increase in temperature within the range 27° to 72.5°F. Above 70°F to 92.7°F there was an actual increase in the butterfat test.

The integration study of Espe (1946) summarised the findings of various work on seasonal trends in yield and composition due to changes other than feed and showed that the butterfat percentage was 15 to 20 percent less in summer than winter and listed high air temperature as one of the main factors concerned.

Hancock (1954) cited the work of Clothier (1919) and Hooper (1925) wherein there was no evidence that the butterfat percent declined with rise in temperature.

Field data on variation of the freezing point of milk with season or linking osmotic disturbances with temperature change is rather limited.

Elsdon and Walker (1942 - Table 86 p. 104) and Davies (1939 - Table CIV p. 287) presented figures for the freezing point depression of milk (average; ordinary range and extreme range values) published by various observers, which indicate the rather wide limits of variation in osmotic pressure.
The investigations of Hortvet and Bailey (Elsdon and Walker - Tables 87 and 88) point to the association of higher freezing points with minimum solids-not-fat percent (corresponding values for individual cows and herds).

The work of Denis - Lester (1936) and Stubbs and Elsdon (1934) recorded wide and similar variations from month to month but could not discern any rhythmic seasonal variation. Stubbs and Elsdon insisted that there was no correlation between the freezing point depression and solids-not-fat content and that hot and dry periods of weather did not materially influence the freezing point value of milk.

Seasonal changes in the osmotic behaviour of milk are more likely to be revealed where studies, instead of being confined to samples of milk of different animals, breeds or different groups of animals, are based on repeated examination of milk from the same animals or the same herds or the same supply, over such a period of time which allows the components of climate to alter considerably with change in season.

Buchanan and Lowman (1929) showed a distinct seasonal variation, the freezing point depressions (monthly averages - mixed herd milk) being greater in winter than in spring and summer but that the range of variation for monthly means was of similar magnitude.

Aschaffenburg and Veinoglou (1944) recorded a series of results of determinations of the freezing point depressions of the milk of individual cows over an extended period of 16 months.
Significant seasonal trends were observed with a marked tendency to unusually low depression values in the spring and early summer, confirming previous work of Aschaffenburg and Temple (1941). It was concluded that the effect was due not to the season as such but to a factor connected with it.
Differences between morning and evening milk followed systematic trends. During summer and autumn, average morning values were persistently less than the corresponding evening values and this relationship was linked with changes in the environmental temperature to which the cows were exposed. At all times the higher depression was obtained at the milking following that period of the day when the temperature was warmest.
No relation could be detected between milk yield, and only low positive correlation between the solids-not-fat content, and its freezing point depression.

Rees (1949) reported that the freezing point depression of two bulk market milk supplies varied in a similar manner with season as did the solids-not-fat, having in common maximum values in late spring and early summer and rapidly declining to minimum values in late summer. The solids-not-fat were temporarily depressed below and the freezing points elevated above the legal standards during this period, which was relatively hot and dry.

The later study by Rees (1952) showed that with progression of lactation in spring and summer, changes in solids-not-fat and the freezing point were highly correlated and confirmed those previously recorded for bulk milk change during the same seasonal period.
During summer, the solids-not-fat and freezing point depression values of evening milk significantly decreased prior to morning milk and in both instances the lactation curve interactions with air temperature were shown to be strongly complementary. Such reciprocal variation with temperature was not regarded as fortuitous but as reflecting a direct and positive reaction of the lactating cow to further temperature increase above the accepted zone of thermoneutrality as during this period of change, feed character in the field was relatively constant. Pasture was in the dry stubble condition.
Drastic alteration in composition and osmotic equilibrium was initiated when maximum and minimum temperatures (weekly means) showed progressive and respective increases from 70°F to 83°F and 53°F to 60°F. The steep character of the lactation curves illustrated that the solids-not-fat and freezing point depression changes were rapid and that minimum values were associated with peak maximum and minimum temperatures.

Under conditions of air temperature increase to maximum and sustained summer levels, it was advanced that the dairy cow may show a greater degree of hyperthermy during day-time milk elaboration (p.m. milking) which, if operative, would reflect the earlier initiation of milk composition and equilibrium changes shown by the evening milk.

Tucker (1963) investigated freezing point variation of individual and herd milk samples from five herds (A.I.S.; Jersey and Guernsey breeds) in the tropic zone of North Queensland and recorded a significant change with season of the year.
During the normal dry spring and early summer months (August to December) the mean monthly freezing point depression progressively increased, remained relatively constant but greater than 0.550°C during summer and early autumn (December to May) and then decreased during the tropical winter to minimum values.
These results indicated lower freezing points of milk in the hottest months, an observation contrary to that recorded by Buchanan and Lowman (1939) and Rees (1949).

Data from the referred literature strongly indicates that decline in milk production, composition (butterfat and solids-not-fat) and production of milk solids (fatty and non-fatty) are associated with high summer temperatures, that the summer depression is a world-wide occurrence and intensifies under drought conditions.

In tropical countries, other environmental factors responsible for unsatisfactory milking performance of European breeds of dairy cattle may be a lower plane of nutrition than in their native habitat, acute infectious tropical diseases and primitive management (Rice 1965).

III EFFECTS ON BLOOD COMPOSITION AND EQUILIBRIUM

The available information indicates that when cattle are under heat stress, changes do occur in blood.

Best and Taylor (1950: human physiology) and Dukes (1947: animal physiology) state that a material decrease in concentration of blood solids results from vascular adjustments involving blood redistribution and increase in blood volume, the plasma volume being considerably increased by water drawn into circulation.

Riek and Lee (1948) performed blood analyses associated with exposure of Jersey cows to dry-bulb temperatures of 85° to 110°F and showed a marked fall in inorganic phosphates from 4.96 ± 0.4 to 2.95 m.g. /100 m.l. of blood and a small drop in serum calcium from 10.58 ± 0.66 to 8.64 m.g./100 m.l. of blood. A decrease in blood sugar was recorded but stated to be in no way correlated with rise in temperature. The probable association of decreased blood phosphate and calcium with respiratory alkalosis was advanced, though acid-base balance was not studied.

Bonsma et alia (1940) asserted that in tropical countries the haemoglobin index decreases, the blood sugar level increases and that the alkalinity of the blood, its non-protein nitrogen and serum calcium content tend to be high. During hot weather the blood chloride content decreases with rise in atmospheric temperature. No results were presented to support the statements.

In the Phillipines, Manresa and Falcon (1939) and Manresa et alia (1939;1940) found that the haemoglobin level of imported temperate breeds and Zebus tended to decrease as air temperature rose and claimed that haemoglobin determinations could be used as a measure of adaptability to environment. Claim was also made that the specific gravity of blood, the serum phosphorus-calcium ratio and the number of red blood cells were lowest and levels of uric acid, serum phosphate and size of red blood cells highest, in animals of poor adaptability.

McDowell (1958) cited studies by Kunkel et alia (1953:1957) with Holstein and Jersey cows during winter and summer which showed significant breed differences for glutathione and glutathione-haemoglobin ratio and seasonal differences with respect to glutathione, alkaline phosphatase and glutathione-haemoglobin ratios. Significant negative correlations were found between haemoglobin and current levels of milk production.

Brody et alia (1949) studied blood composition changes in Jersey and Holstein cattle from temperatures of 50° to 100°F and concluded that increase in temperature had little or no effect on blood serum calcium haemoglobin, magnesium and plasma protein. The level of blood glucose showed a disorderly fluctuation with a detectable decline at 90°F.

Values for CO_2- capacity of blood plasma began to decline about 85°F as did blood cholesterol and non-protein nitrogen. Blood inorganic phosphorus and creatinine increased above air temperatures of 85°F and 80°F respectively.

Blincoe and Brody (1951) reported that high haemoglobin values were associated with high adaptability to extreme conditions of temperature, which was also true of specific gravity, the ratio of calcium to phosphorus and the number of erythrocytes and in which Rusoff et alia (1951) were in agreement.
Blincoe and Brody further reported a critical temperature of 65°F above which obvious changes in blood occurred viz:- marked increase in creatinine and marked reductions in the ascorbic acid and cholesterol levels. These changes were associated with reduced feed intake.

In their integration study, Worstell and Brody (1953) suggested that the decline in CO_2- combining capacity of blood plasma observed by Brody et alia (1949) appeared to have been caused mostly by loss of carbon dioxide following increase in pulmonary ventilation rate and that the rise in creatinine and reduction in the ascorbic acid blood levels recorded by Blincoe and Brody (1951) reflected

(a) accelerated endogenous nitrogen catabolism following the decline in feed consumption and increase in rectal temperature, in the case of creatinine increase

(b) the reaction of the adrenal cortex to heat stress, in the case of ascorbic acid reduction.

Dennis and Harbough (1948) recorded the strong tendency for blood plasma CO_2- capacity to decrease in hot weather, when temperatures exceeded 85°F.

Observations of decline in values for CO_2- capacity of blood plasma would be important in indicating a shift in the acid-base balance of blood to alkalinity while the animal is in heat stress.

Temperate breeds of dairy cattle under the influence of heat stress exhibit polypnoea or panting, the depth of breathing decreasing compared to that when the cow is in thermal equilibrium with its environment and when normal respiration rate and character prevail.

Findlay (1950) considered that decrease in depth of respiration normally enables the dairy cow to increase the rate of ventilation without over-ventilating the alveoli and that this latter condition would lead to apnoea or blood alkalosis due to excessive loss of CO_2.

Bianca (1958) suggested that with prolonged exposure to heat stress, cardiac acceleration may result from an increased demand for oxygen by the respiratory muscles and that extended hyper-ventilation, while resulting in some cooling of the body, may place a strain upon the heart as well as adding to the danger of induced alkalosis of the blood through excessive depletion of CO_2.

Laboratory studies by Brody (1956); Johnston et alia (1955); McDowell et alia (1953) and Lee and Phillips (1948) have indicated that the respiration rate and volume do not increase in the same proportion with air temperature increase, and confirm the opinion that high respiration rates may develop a respiratory alkalosis with a decline in the CO_2^- combining power of the blood.

Barrada (1957) has shown that cattle appear to have the ability to compensate for the alkalosis, except under severe conditions (100°F and humid) through the excretion of alkali by the kidneys.

Blood and milk are accepted as being isotonic fluids and blood changes may be related directly or indirectly to milk changes.

Wheelock, Rook and Dodd (1965) investigated the relationship in the cow between the osmotic pressure of milk and blood, osmotic changes being measured by freezing point determinations conducted on jugular and mammary venous blood and milk.

Results indicated that milk is in osmotic equilibrium with blood flowing through the udder, continuously throughout the period the milk remains in the udder and that milk secretion causes a slight change in osmotic pressure of fluids within the immediate locality of the mammary gland.

IV EFFECTS ON FEED CONSUMPTION AND GRAZING HABITS

(a) Effects on Feed Consumption

Data from psychrometric room studies by Ragsdale et alia (1948:1950) uniformly indicated the decrease of feed intake with temperature increase to high levels (75° to $105^{\circ}F$) and that this decline paralleled and reflected decline in milk production and was associated with loss of body weight.

Ragsdale et alia (1953) and Brody et alia (1954) showed that increasing humidity and radiation had the same effect at temperatures which caused rectal temperatures to rise but that milk production decreased sooner and more rapidly than feed intake.
The latter workers established that increasing radiation intensity to a level of 180 B.t.u./hr. $ft.^2$ increased the depression at lower temperatures ($70^{\circ}F$ and $80^{\circ}F$) and slight decreases in body weight were recorded.

Worstell and Brody (1953), in their summary of feed consumption studies, showed greater decreases in feed consumption than milk production by curves resulting from plotting feed consumption and milk production against rectal and air temperatures and by the ratio curves of the total digestible nutrients consumed to the fat corrected milk (4 percent) produced. The greater decline in feed consumption leads to loss in body weight. It was advanced that the slight decline in body weight was due in part to replacement of the body fat by water and in part to decline in the maintenance cost (decrease in heat production). The Jersey, Holstein and Brown Swiss cows lost weight but the Brahmans maintained weight and all animals gained weight with declining temperatures. Declines in feed consumption and milk production were considered as homeothermic mechanisms reducing thermal stress associated with feeding and lactation.

Ragsdale and his colleagues favoured partition of the factors causing milk production decrease into:-

(a) decrease in feed consumption associated with temperature increase

(b) increased temperature acting directly on the mechanism which limits milk production.

Brody (1945) strongly supported the effect of the former factor, because cattle in the extreme post-absorptive condition (no food in the digestive tract) virtually ceased milk production.

Wayman et alia (1962) compared constant intake with force-feeding at 65°F and 85°F (the latter temperature effected a 2°F rise in the rectal temperature of lactating cows) and their data supported a direct and indirect influence of the higher temperature. The major decrease in milk production was due to reduced feed intake but high temperatures caused a significant decrease ($P < 0.05$) in efficiency of energy utilisation.

Mills and Ogle (1939) and Brobeck (1948 (a) : b) concluded that the control of food intake is one of the natural mechanisms of temperature regulation.
Brobeck asserted that the amount of food eaten appears to be determined, at least in part, by the organism's ability to dissipate the heat of metabolism (Rubner's specific dynamic action).

Negi and Mullick (1960) also reported on depressed appetite in cattle caused by high environmental temperature.

(b) Effects on Grazing Habits

In the field, the effects of temperature and radiation on the grazing habits of dairy cattle are important in explaining increase or decrease in milk production. The seeking of shade and a voluntary reduction in food intake by the cessation of grazing are physical homeothermic mechanisms which ease the burden of heat load put upon the animal (Findlay 1950).

Atkeson et alia (1942) recorded that the comparative time spent in grazing by milking cows was related to pasture condition. Slightly less than half the time (5.6 hrs.) was spent in grazing good pasture, 55 percent (6.5 hrs.) on fair pasture and 62 percent (7.3 hrs.) on poor pasture. The daylight period on pasture was 11 to 12 hours.

The proportion of the day spent by temperate breeds in grazing has also been reported by Hodgson (1933); Giobel and Lindbom (1933) and Johnstone-Wallace and Kennedy (1944). These studies did not include the effects of climatic factors on grazing habits and times.

Seath and Miller (1946) did investigate the effect of warm weather on the grazing performance of milking cows (Jerseys and Holsteins) during the day (shade and sunlight) and night. The average day temperature varied from 72° to 86°F and night temperature 62° to 81°F; day recordings were at 8.30 a.m. : 11.30 a.m. and 2.30 p.m. and night recordings at 6.30 p.m. : 12.30 p.m. and 3.30 a.m.
With day-time temperature increase (73° to 86.7°F) and relative humidity decrease (89.3 to 65.3 percent) there were increases in body temperature (101.7° to 103.5°F) and respiration rate (63 to 79 per min.) but the pulse rate remained relatively constant (66 to 67 per min.). Cows ceased grazing and sought shade when air temperature was 80°F (rise of 7°F), relative humidity 81.3 percent (fall of 8.0 percent) and when body temperature rise was initiated (102.4°F).

Day-time grazing performance when average day temperatures were 85.5°F, were:- grazing - average 1.85 hours; non-grazing (in shade) - average 5.6 hours.
Night grazing performance, when night average temperatures were 76°F, were:- grazing - average 6.35 hours; non-grazing 3.45 hours.
The night grazing periods exceeded the day-time periods by a ratio of more than 3 to 1. The total daily grazing periods whilst on pasture were:- grazing - average 8.2 hours; non-grazing 9.05 hours. The average day-time grazing significantly increased (approximately 2.5 times) with fall in the average temperature of 86° to 72°F and 81° to 62°F for day and night respectively; night grazing decreased and the total 24 hour grazing periods showed increases in grazing time due to cool weather, of more than one hour daily.

Rhoad (1938) and Bonsma et alia (1940) reported on the grazing performance of temperate, tropical and cross-bred beef cattle over the temperature range 76° to 103°F under shade and non-shade conditions and concluded that grazing times were related to the amount of tropical blood.

Studies on grazing habits thus indicate that heat stress induced by exposure to high air temperatures and direct solar radiation is related to restriction of normal grazing performance and that there are striking differences in the heat tolerances of various breeds and between temperate and tropical breeds, grazing times being least in the temperate breeds.

V EFFECTS ON WATER CONSUMPTION

The physiological need for water to replace losses incurred through such agencies as lung and skin evaporation, salivation, urination and defaecation is very great during active heat dissipation and the ability of homeotherms to regulate body temperature is largely due to water of the blood and tissue fluids. The thermostatic properties of water (highest specific heat of all substances, high heat conductivity and very high latent heat of evaporation) make it ideal as a heat regulating medium, enhanced by other purely physiological factors.

Winchester and Morris (1956) summarised the research studies of Brody et alia (1954); Ittner et alia (1951 and 1954); Kelly et alia (1955) and Ragsdale et alia (1950:1951:1953) on the effects of environmental temperature and other relevant factors on the water requirements of dairy cattle in constant temperature chambers at a mean temperature of 90°F. Generally, water consumption for a given animal remains constant as temperatures increase from 10° to 50°F, increases at an increasing rate above 50°F and very nearly doubles in the temperature range 80° to 95°F.
Individual cows differ widely in the quantities of water consumed. Thompson, Worstell and Brody (1949) recorded that the respective water consumption rates of three Jersey cows, similar in size, stage of lactation and under identical environmental conditions and management were 40, 25 and 14 gallons per day at an air temperature of 95°F and analogous differences were maintained at variant air temperature levels within the range 85° to 105°F.

The specific studies of Ragsdale et alia (1949:1951:1953) showed that water consumption tended to parallel feed consumption below 85°F and that cows consumed less water at higher humidity levels during temperature variation from 75° to 100°F, which reflected in part lower moisture vapourization at the higher humidities and in part lower feed intake and milk production. The frequency but not the amount of drinking tended to increase with increasing restlessness of the animals while in heat stress.

4. DESCRIPTION OF THE PSYCHROMETRIC ROOM

GENERAL DESIGN AND FEATURES (Reference Plates 2 - 5 incl.)

Two independent stalls, each 12'0" x 8'0", with ceiling 8'0" sloping to 7'0", were equipped with feed and water troughs and facilities for machine milking (intra and extra unit), feed storage and calculation of feed and water consumption. The concrete floor was covered with 6" bedding of buzzer chips and the ceiling and walls with 3/16" Burnie hardboard, faced with heat and humidity-resistant white paint and insulated with 0.004" visqueen.

Milking facilities consisted of a two unit bucket type, conventional slide pulsator milking machine; pulsation ratio 30/70 squeeze-release; rate 45 pulsations per minute.

Natural lighting was provided by three windows (3' x 3') and two 8'0" sheets of corrugated perspex, one centrally located over each stall.

Heating was generated by four thermostatically controlled industrial unit heaters, (each of 3 kilowatts), fan type, diagonally located, and connected in parallel. The installation was modified to minimise velocity of heated air in the immediate vicinity of the cow.

Uniform ventilation was provided by a $7\frac{1}{2}$" exhaust fan, XPELAIR type with diaphragm and four speed regulator. Constant operation of the fan at the minimum exhaust setting of 150 cubic feet of air per minute ensured an adequate margin ($12\frac{1}{2}$%) above the air ventilation standard of 4,000 cubic feet per cow per hour, prescribed for dairy cows in milk and fully housed.

The following recording instruments were installed; Casella thermohygrograph, with mercury-in-glass and wet and dry-bulb thermometers for standardisation; maximum and minimum thermometers; kata-thermometer for determination of air velocity.

The Unit was not equipped with refrigeration. Trials were initiated in late autumn and continued through winter when external ambient temperatures were always materially lower than the minimum trial temperature. This ensured that the lower trial temperatures could be maintained and the uniform ventilation system effected rapid temperature reduction when required.

PLATE 1 - Experimental cows at pasture

PLATE II - External layout of the psychrometric room (centre):

Extra-unit milking shed (left):

Dairy (right).

Easterly aspect

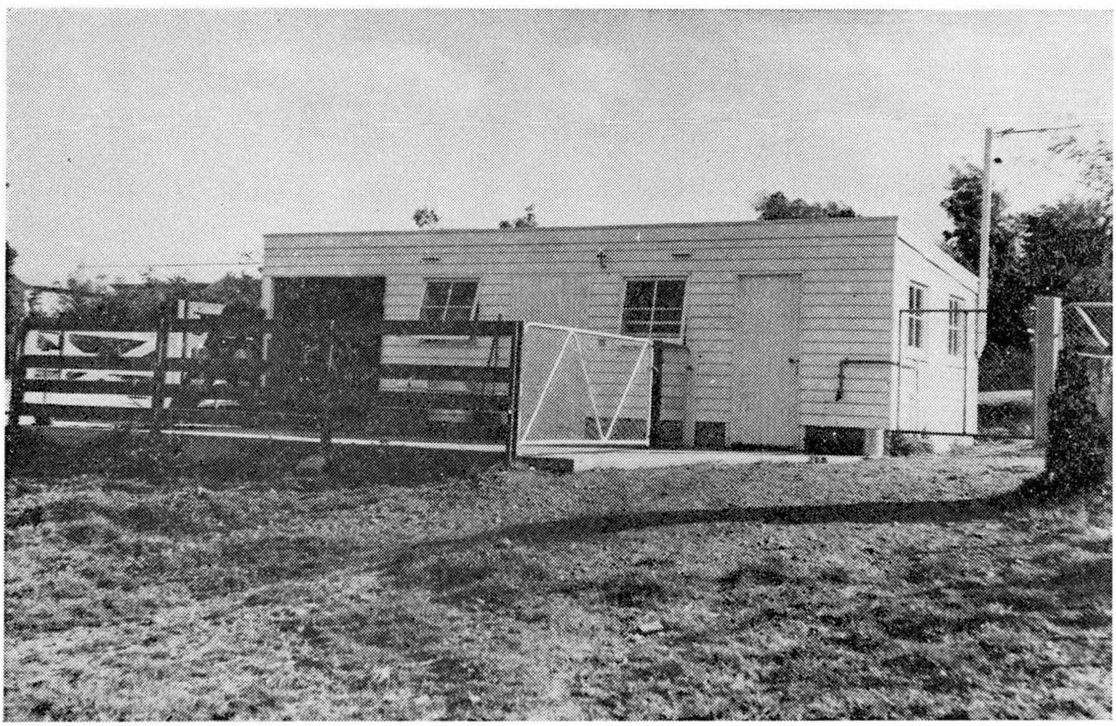
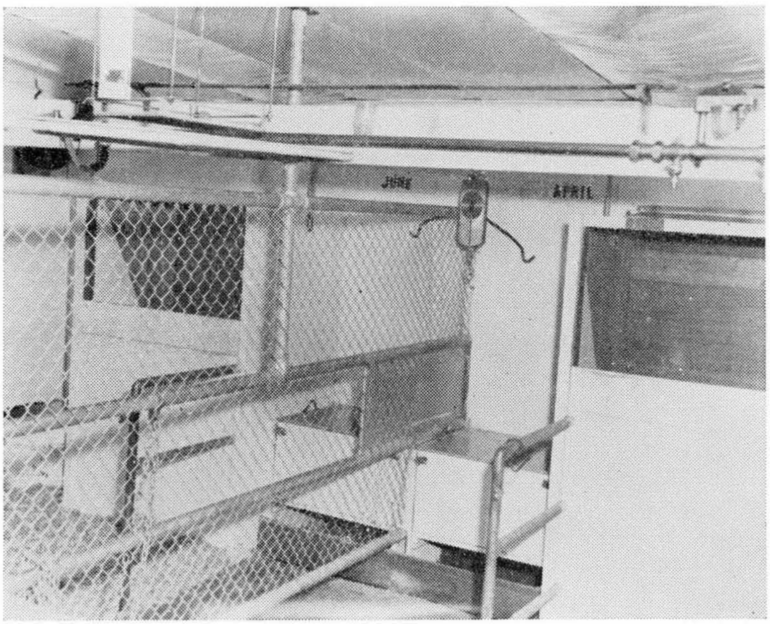


PLATE III - Internal design of the psychrometric room



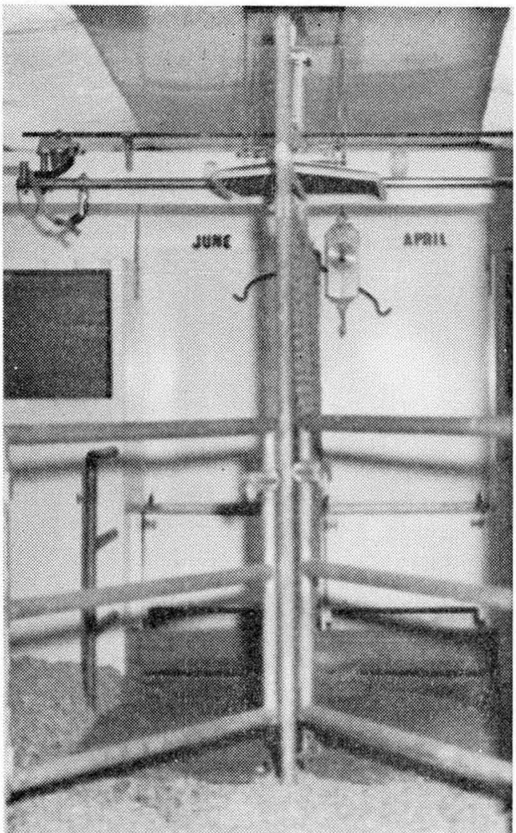
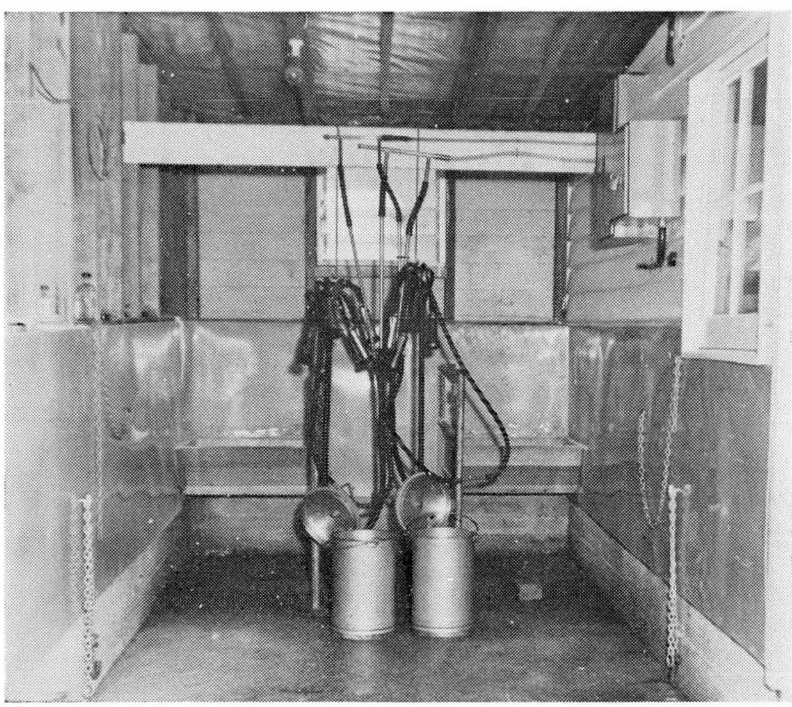


PLATE IV - Internal design of the psychrometric room

PLATE V - Extra-unit milking facilities



5. MILK COMPOSITION; MILK EQUILIBRIUM AND PHYSIOLOGICAL RESPONSE

PART I

THE INFLUENCE OF CONSTANT AMBIENT AIR-TEMPERATURE

Experimental Procedure

By design, four cross-bred heifers were inseminated to calve as rising three-year-olds in the late autumn-early winter. Each was brought under test observation 1 - 2 weeks after parturition, to determine attainment under field conditions of reasonably stable values for the test determinations pertinent to the trials. Observational testing varied from 4 - 8 weeks, influenced by calving dates and experimental cow grouping.

FEED

The following standardised feeds and feeding practices were adopted under Trial and Field conditions.

(a) Trial

Two experimental cow groups were established with respect to feed treatment.

TABLE 1

Group	Cow Designation	Breed Type	Trial Ration
A	A1	Jersey x Friesian	High Protein (H.P.) Concentrate + chaff
	A2	Jersey x Friesian	
B	B1	Jersey x Ayrshire	Low Protein (L.P.) Concentrate + chaff
	B2	Jersey grade	

The concentrate mixtures were prepared as follows :

TABLE 2

Concentrate Mixtures

Feed	Parts by Weight	
	High Protein (H.P.)	Low Protein (L.P.)
Bran - wheaten	6	6
Oats - ground	2	4
Pea meal (blue)	4	
Linseed meal	2	

The Trial rations were compounded in the following proportions by weight:

TABLE 3

Trial Rations

Trial Ration	Composition by Weight	
Ration X (H.P. Concentrate + chaff)	H.P. Concentrate	14
	Oaten chaff	18
Ration Y (L.P. Concentrate + chaff)	L.P. Concentrate	10
	Oaten chaff	30

The average composition and food values for Trial Rations "X" and "Y" and concentrate mixtures, are presented in Table 1 - Appendix.

Trial Ration "X" was designed to be reasonably balanced and "Y" unbalanced for milk production. (Nutritive Ratios 1 : 5.9 and 1 : 9.8 respectively).

Ration "Y" was compounded in this manner to ascertain whether the influence of temperature was independent of, or modified by feed quality. It was designed to simulate the qualitative and quantitative character of feed available from grazing of improved pasture under the relatively dry and hot seasonal conditions of mid-late summer.

(b) General

For a period of one month pre-calving, each cow was fed 4 lb. H.P. Concentrate/diem; all cows calved normally and were in excellent condition.

Routine feeding in the field during lactation comprised :

(a) 6-8 lb. H.P. Concentrate/cow/diem - according to milk production;

(b) rotational grazing from two 2-acre areas of improved pasture (ryegrass and white clover) ;

(c) grass-clover hay always available to full appetite.

(c) Pre-Trial - Field

For 2 weeks the appropriate Concentrate (H.P. or L.P.) related to the specific Trial Ration for each cow, was introduced into the routine feeding schedule, followed by 1 week of controlled change from Field to Trial feeding, viz: gradual limitation of green feed, hay and concentrate and final total replacement with handfeeding the specific Trial Ration.

(d) Post-Trial - Field

The reverse procedure of (c) and the feeding schedule extended to 3 weeks.

TEMPERATURE

Trial Design

The effect of ambient temperature on the composition of milk, freezing point and inherent titratable acidity values was investigated by exposing the cows to controlled ambient temperature levels within the range 70°F to 105°F.

Index of thermal stress was obtained from measurement of body temperature (rectal), respiration and pulse rates at each temperature level.

Ambient temperature control was maintained within the range T$^{\circ}$F $\pm$ 2°F. The duration of exposure in days for each thermal level is presented in Table 4.

TABLE 4

Trial No.	Cow	Trial Ration	Initial Control Period Ambient Temp. 51° - 62°F	Temperature $^{\circ}$F $\pm$ 2°F													Final Control Period Ambient Temp. 51° - 62°F
				70	75	80	85	90	95	100	105	100	90	80	75	70	
I	A1 B1	X) Y)	4	2		2		2		2	2	2	2	2		2	4-Days
II	A2 B2	X) Y)	4		2		2		2		2	1			2		4-Days

The design for Trial II was altered, in the light of results and experience gained in Trial I, with a view to :

(a) Obtaining more precise information on the temperature level which first induced permanent body temperature increase and milk change;

(b) Determining whether reduction in the duration of exposure to "critical temperatures" would modify the recovery of test values when temperature levels were returned to control conditions.

Relationship to Relative Humidity

Air moisture content of the psychrometric room was not standardised to uniform and defined limits during temperature variation.

Pre-trial experience demonstrated that humidity decreased with ambient-temperature increase, which simulated humidity decrease in the field normally associated with hot weather and high pressure systems in mid-late summer.

In the experiments, this effect was achieved. Ventilation rate was standard throughout the trials and air moisture expressed as relative-humidity.

Thus reference to a specific temperature implies also a specific relative-humidity level, which is presented in Table 5.

The relative-humidity indicated for each temperature was derived by simple averaging of mean daily minimum and maximum values. Maximum relative-humidity invariably occurred at night (6 p.m. - 9 a.m.) and minimum during the day (9 a.m. - 6 p.m.).

During the Control periods, 56.5°F ± 5.5°F, relative-humidity varied considerably, 80.0 ± 10.0%, but this variation was materially reduced when artificial heat was applied.

TABLE 5

Temperature - Relative-Humidity Relationship

Trial Period	Temperature °F	Relative Humidity %	Relative Humidity % Variation
Experimental-regulated temperature	105 ± 2.0	36.0	± 1.0
	100 "	36.5	± 1.5
	95 "	51.0	± 1.0
	90 "	47.0	± 2.0
	80 "	58.5	± 2.5
	75 "	76.5	± 0.5
	70 "	71.0	± 2.0
Control	56.5 ± 5.5	80.0	± 10.0

DETERMINATIONS AND METHODS

Trial records were obtained for the following:-

(a) Milk. Test values were secured for p.m. and a.m. samples; p.m. samples were refrigerated overnight. Milking interval times were standardised at 5.00 p.m. and 8.00 a.m. and test determinations initiated 1 hour after a.m. production.

1. Yield (Y) - expressed in pounds (lb.).
2. Total Solids percentage (T.S.%); determined by gravimetric method (Analyst 70 : 105 : 1945).
3. Fat percentage (F.%); determined by the Babcock method (Aust. Standard No. N26 - 1958; Standards Assoc. Aust.).
4. Solids-not-Fat percentage (S.N.F.%) calculated by difference.
5. Freezing Point ($\Delta^{\circ}C$); determined by the Hortvet Cryoscopic Method. (Methods of Analysis. A.O.A.C. 8th Ed. 1955 15 : 30 : 31 : 32 : p. 250 - 253).
6. Inherent Titratable Acidity (referred to as acidity); 9.0 m.l. of milk were diluted with an equal volume of distilled H_2O and titrated with standard 0.1N NaOH, using 0.5 m.l. phenolphthalein indicator (1.0% solution in C_2H_5OH). The acidity was expressed as percentage by weight of lactic acid, (Methods of Analysis. A.O.A.C. 8th Ed. 1955 15.4 p. 242), being normal procedure in milk chemistry.

Lactic acid development due to biological fermentation of lactose was restricted (confirmed by check testing) and thus the titratable acidity of milk represents the quantity of lactic acid equivalent to the alkali required to change the pH of the various milk buffer systems from normal and original pH values of about 6.6 to that of 8.3. It is a measure not only of true acidity or pH but also of the buffering power of the milk over this pH range. Hence, changes in acidity values reflect changes in concentration of buffer constituents inherently present in the milk.

The significance of this test lies in the fact that true acidity, with temperature, are the two most important factors controlling the behaviour of milk and its derivatives in the various processes employed in the dairy industry.

(b) Physiological Measurements. These were recorded daily under standardised conditions, viz. readings taken with the cow standing 1 hour after the a.m. milking.

1. Pulse Rate (P.R.) was expressed as the average pulse-rate per minute, taken from two 1 minute readings by:-
   (a) digital palpation of the radial artery, and
   (b) auscultation over the chest, utilising the stethoscope.

2. Respiration Rate (R.R.) was recorded by observation of flank movement, each complete inward and outward movement constituting one complete respiration. The average of two uninterrupted 1 minute recordings expressed the respirations per minute.

3. Body Temperature was measured as rectal temperature (R.T.$^{\circ}$F). The clinical thermometer was inserted to a standard depth (4") for a minimum of 2 minutes and contact between rectal walls and thermometer ensured.

4. Rumenal Movement was measured by auscultation and expressed as movements per minute.

(c) Water and Feed Consumption were recorded on a daily basis and feed bins and water troughs replenished twice daily.

(d) Supervision of Animal Health. Under field and trial conditions, the incidence of udder abnormality was checked weekly by aseptic withdrawal of consecutive p.m. and a.m. quarter milk samples and their subjection to microscopic and cultural examination, using for the latter Edward's blood-agar medium.

Daily veterinary inspection of cows was made, concurrent with securement of physiological measurements.

- - - - - - - - - - - -

The absence of mastitis as a factor which can produce drastic changes in milk production, composition and acidity, is necessary in investigations of this nature. No evidence of mastitis or of udder abnormality could be demonstrated in this work and while the experimental cows were under thermal stress, veterinary opinion did not indicate at any time that the related temperature-time exposure was dangerous to animal health.

Results

SECTION I

% Solids-not-Fat (S.N.F.) (Reference Figure 1 and Appendix Tables 2-5 incl.)

Freezing Point Depression (Δ) (Reference Figure 2 and Appendix Tables 2-5 incl.)

Inherent Titratable Acidity (A) (Reference Figure 2 and Appendix Tables 2-5 incl.)

Yield (Y) (Reference Figure 6 and Appendix Tables 2-5 incl.)

Explanation:

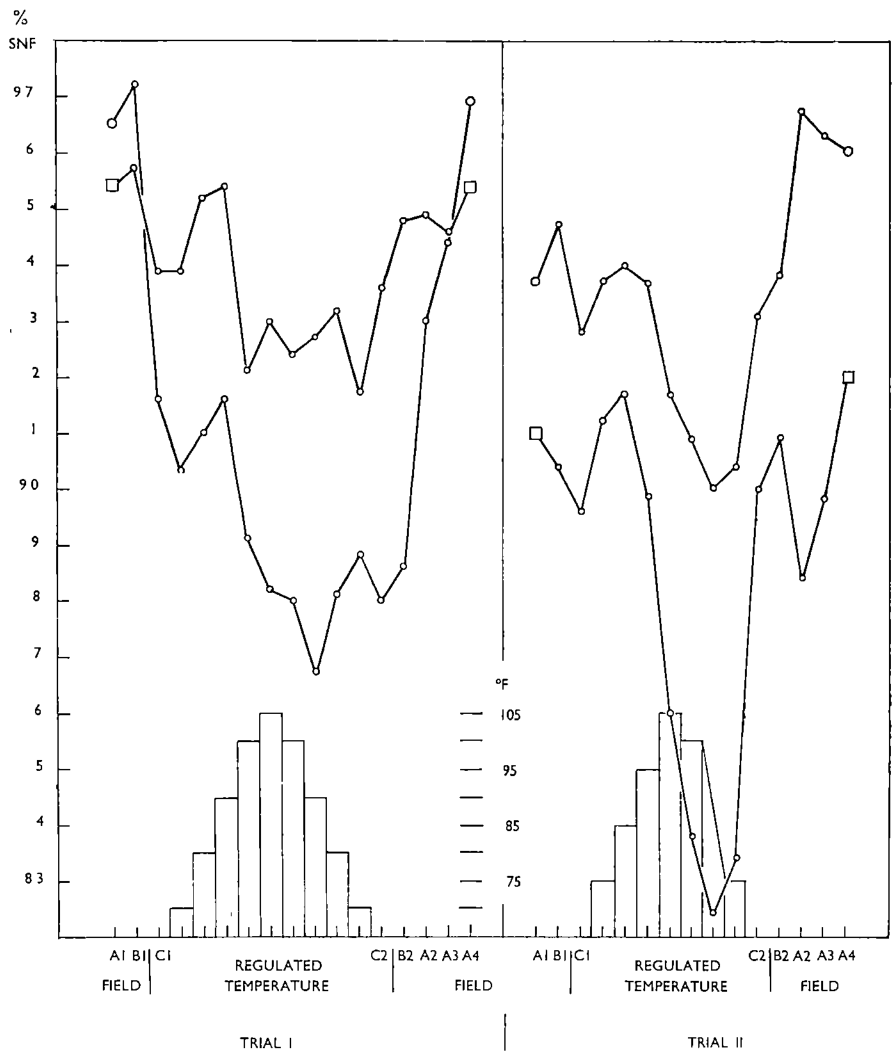
(a) As variations in fat content are reflected in variations of the solids-not-fat of whole milk, S.N.F. values have been expressed and utilised in Figure 1 as solids content of the fat-free serum.

(b) Decrease in Δ value denotes elevation of the freezing point of milk.

All numerical test data is presented as weighted daily averages (p.m./a.m. production) for the entire period of exposure to a specific temperature or environment (field or house condition) as per experimental design.

FIGURE 1

Effect of Air-Temperature on % Solids-not-Fat (S.N.F.)
(Values are weighted daily averages P.M./A.M. production
expressed on the Fat-Free-Serum (F.F.S.) basis)



Legend for Figures 1 - 6 inclusive.

Values for non-regulated temperature, trial conditions -

A1 Pre-Trial environment; routine field feeding; period 7 days.

B1 Pre-Trial environment; regulated change to trial feeding; period 7 days.

C1 Initial Trial Control Period.

C2 Final Trial Control Period.

B2 Post-Trial environment; regulated change to field feeding; period 7 days.

A2)
A3 } Post-Trial environment; routine field feeding;
A4) period each of 7 days.

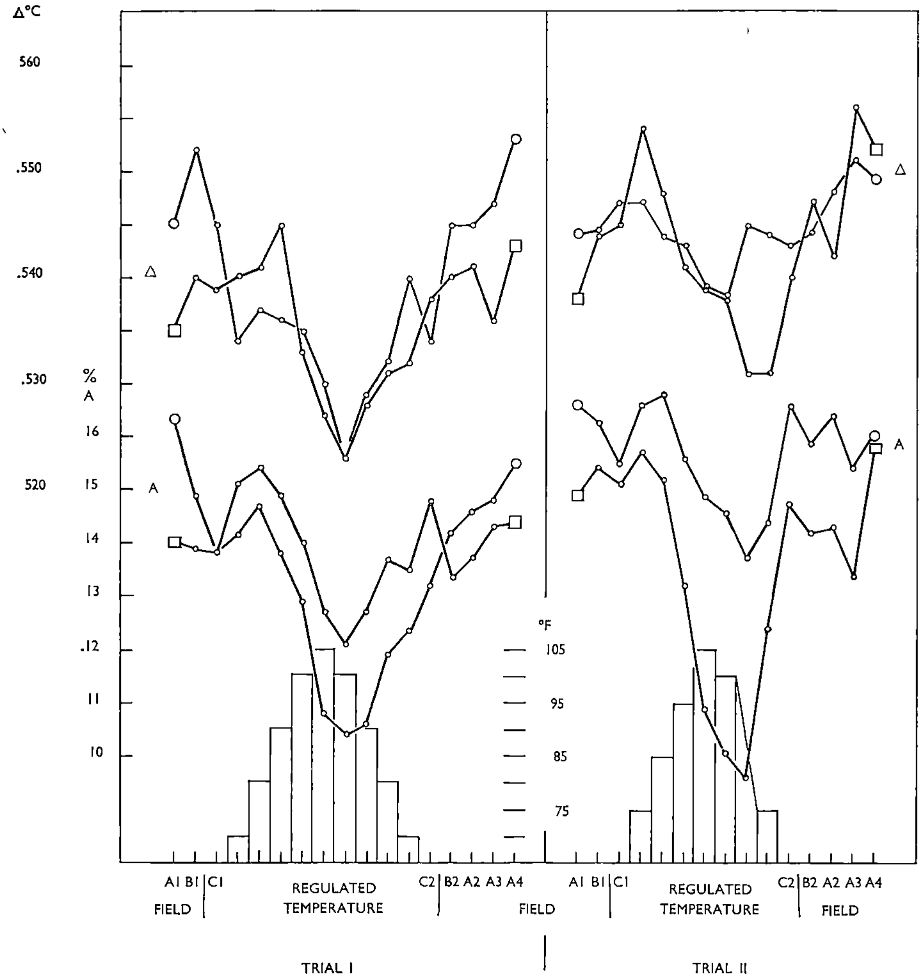
Feed-Treatment -

- o - Trial I - Cow A1; Trial II - Cow A2;
Trial Ration X - high protein concentrate + chaff.

O - o - O Trial I - Cow B1; Trial II - Cow B2;
Trial Ration Y - low protein concentrate + chaff.

FIGURE 2

Effect of Air-Temperature on Freezing Point Depression (Δ°C); Inherent Acidity (A) expressed as % lactic acid equivalent. (Values are weighted daily averages P.M./A.M. production). Legend and Feed Treatment - as per Figure 1.



Changes involving feed treatment, environment, &c., under field conditions and during transference of stock to the fully-housed state, are shown to effect differential readjustment of field test levels. During this period of adjustment, involving common denial of green pasture grazing, the effect of Ration Y (low protein concentrate + chaff) was generally less favourable than Ration X (high protein concentrate + chaff). Values stabilised during the initial Control Period (C1).

Exposure to regulated increase and decrease in ambient air-temperature, resulted in S.N.F., Δ and acidity trends conforming to a common and definite pattern, the nature of which was apparently uninfluenced by feed treatment.

Initially all test values increased or strongly stabilised, as did milk production. Rapid depression occurred when ambient temperature rose above 90°F and 85°F in Trials I and II respectively. The freezing point depression and acidity values decreased at lower temperature levels than S.N.F., which suggests that milk equilibrium change actually preceded alteration in the concentration of the milk-serum solids.

Such behaviour indicates that, for the dairy cows in question, the temperature range of 80°F - 85°F must approximate very closely to the extreme upper temperature limit of the zone of thermoneutrality.

Milk change intensified with temperature elevation within the range $95^{\circ}F$ - $105^{\circ}F$. The magnitude of depression was variable and reflects differential animal response to temperature change; is shown to be independent of feed treatment and to be apparently related to the milk-production of the cows. Within each trial, the decrease in S.N.F., Δ and acidity, was more marked with the cows which initially produced the greater milk yields.

All cows produced milk not conforming to legal standards either in S.N.F. and/or Δ following continuous high temperature exposure.

(Tasmanian Standards) - S.N.F. - 8.50%; Δ not less than $0.540^{\circ}C$. (Food and Drugs Regulations 1941 - Statutory Rules 1960, No. 143. Department of Health Services; Tasmania.).

Values for Δ and for S.N.F. on the whole milk basis, are presented in Tables 2 - 5 inclusive (Appendix).

Minimum values were invariably attained after peak-heat exposure and maintained to lower temperature levels. Thus S.N.F., Δ and acidity values showed marked differences at corresponding levels of ambient temperature increase and decrease. In extreme cases, such differences were maximum.

During temperature reduction, lag in recovery to control levels was most evident with S.N.F. and apparently related to the duration of animal exposure to stress temperature. In Trial I, S.N.F. did not recover, though the trend is indicated. Complete readjustment was effected under field conditions. In Trial II, recovery was complete under trial conditions.

Minimum Δ and acidity values were more closely related in time to maximum ambient temperatures than S.N.F. and their common latent recovery more rapid and complete in both trials.

SECTION II

% Fat (F) (Reference Appendix Tables 2 - 5 incl.)

Production of fat and non-fatty milk-solids (Reference Appendix Tables 2 - 5 incl.).

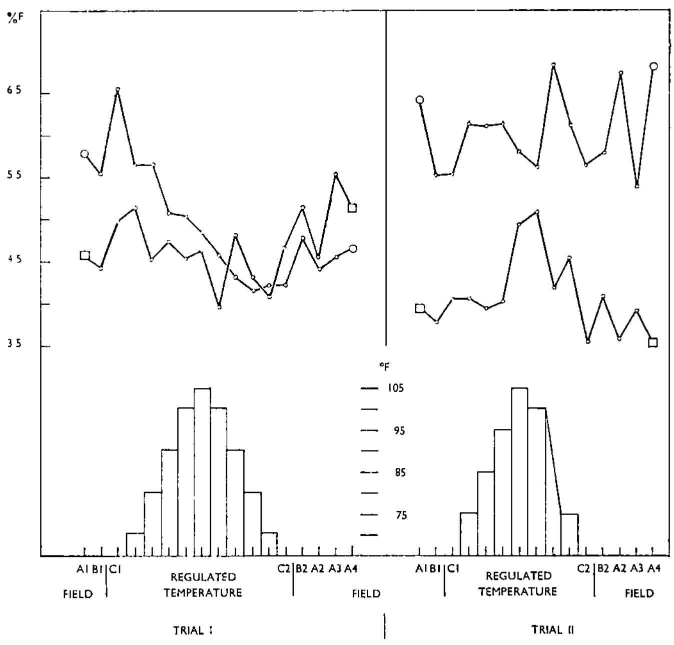
Figure 3 depicts the influence of air-temperature on milk-fat (F) concentration.

The main features are the complete lack of uniformity in % F. variation and an apparent absence of relationship between % F. variation and the common pattern of % S.N.F. behaviour.

The similarity of trends, under the common influence of air-temperature, is disclosed when butter-fat and solids-not-fat productions are compared, as in Figure 4.

Air-temperature increase, either directly or indirectly (through reduced feed consumption), effected a differential depression in the milk yield of all cows (vide Figure 6). Decreased milk yield is thus closely related to the production level of both fatty and non-fatty solids, but apparently not to the fat concentration in milk.

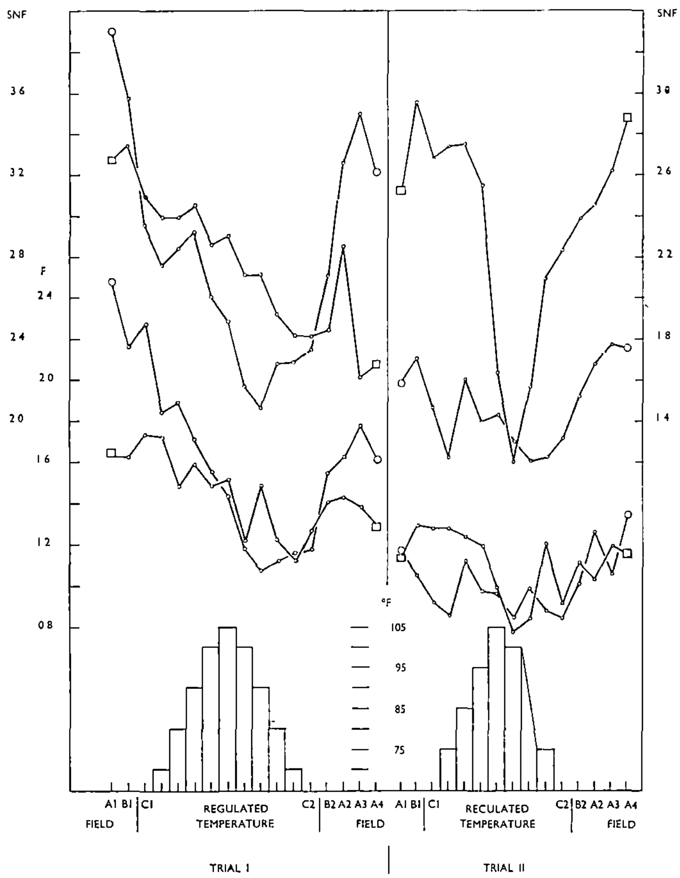
FIGURE 3



Effect of Air-Temperature on % Fat (F). (Values are weighted daily averages P.M./A.M. production).

Legend and Feed Treatment - as per Figure 1.

FIGURE 4



Effect of Air-Temperature on Yield of Fat (F) and Solids-not-Fat (S.N.F.) in the lbs/day. (Values arc daily means). Legend and Feed Treatment - as per Figure 1.

SECTION III

Physiological Variables

Rectal Temperature (R.T.) (Reference Figure 5 and Appendix Tables 2-5 incl.)

Respiration Rate (R.R.) (Reference Figure 5 and Appendix Tables 2-5 incl.)

Pulse Rate (P.R.) (Reference Figure 5 and Appendix Tables 2-5 incl.)

In animal physiology, body temperature, respiration and pulse rates are closely related to air-temperature above certain critical levels, through the balance of body heat gains, and losses (Quartermain, 1962). They are inter-related biologically and a positive change reflects thermal stress.

In this work, their measurement is utilised as a means of evaluating the efficiency of homeothermy and to provide an index of the relationship of heat intolerance and disturbed physiological function with milk composition and equilibrium change.

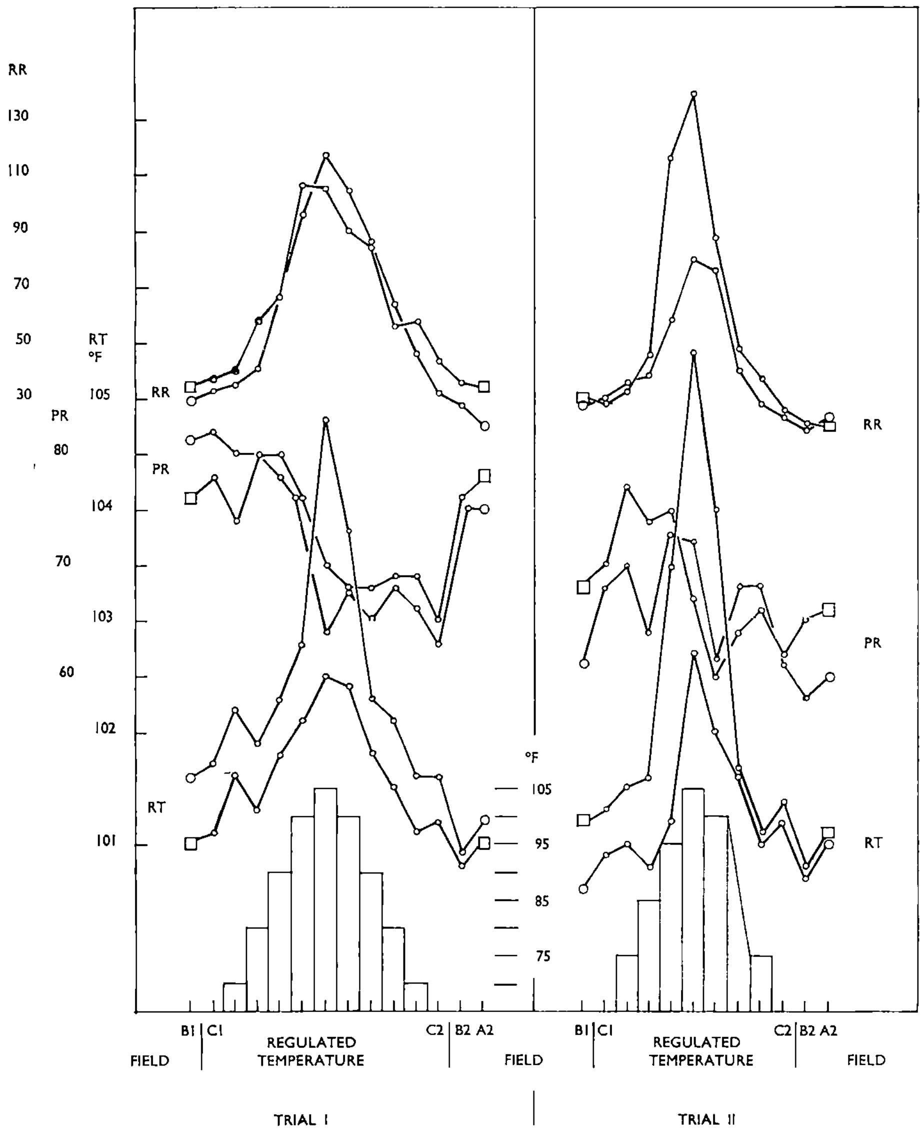
The results depict inability to maintain normal body temperature. Severe disturbances also occurred in respiratory and cardiac function due to thermal stress.

FIGURE 5

Effect of Air-Temperature on Rectal Temperature (R.T. °F.); Respiration Rate (R.R.) and Pulse Rate (P.R.).

(Values are daily averages for each temperature of exposure)

Legend and Feed Treatment - as per Figure 1.



Rectal temperature did not increase significantly until ambient temperatures exceeded 80^{o} - $85^{o}F$, when an induced "fever" condition progressively established. The initial thermal level at which the heat regulating mechanisms were severely overtaxed is shown to be related in time with commencement of milk composition and equilibrium change.

For each physiological variable, animal response to ambient temperature change was similar, fairly rapidly established (especially respiration rate), but variable in magnitude, reflecting the strong influence of cow individuality and in each Trial, greater thermal stress was evident in cows with the higher milk production.

Ambient temperature decrease from $105^{o}F$ to control conditions (51^{o} - $62^{o}F$) re-established normal R.T. and R.R. levels, with no evidence of lag in recovery.

Pulse rate did not show the same trend common to R.T. and R.R. Similar but irregular increase in heart rate (strong stabilisation Cow B1, Trial I) resulted with temperature increase to 90^{o} - $95^{o}F$. Thereafter P.R. fell rapidly, minimum values occurring at 95^{o} - $105^{o}F$. Control levels were not regained during either Trial, the lag in recovery extending to field conditions.

Within the temperature range 95^{o} - $105^{o}F$, significant change in the character of "heart-beat" was recorded, increasing in depth to a full and bounding pulse-rate condition, which however did not persist during air-temperature reduction to control level.

Blood pressure measurements were attempted during this period of "pulse abnormality" using a sphygmomanometer, with attachment of the cuff over the caudal artery. These were discontinued because of obvious animal nervous tension, non-reproducibility of results and the necessity to maintain normal intactness of the animal.

The complementary curve interaction of P.R. with R.T. and R.R. noted during 95° - 105°F exposure, strongly supports the existence of a pyrexial threshold above which animal tolerance to the thermal environment rapidly diminishes. Physiological deterioration coincided with rapid depression of milk-serum characteristics as measured by inherent S.N.F., Δ and acidity levels and such results indicate location of this threshold temperature within the range 85° - 95°F.

The following table presents the degree of correlation between environmental temperature and the physiological variables recorded in this work and are expressed as simple correlation co-efficients.

TABLE 6

Trial	Cow	rX.RT	rX.RR	rX.PR
I	A1	0.81 **	0.88 **	0.001
	B1	0.82 **	0.91 **	-0.25
II	A2	0.94 **	0.93 **	-0.47
	B2	0.82 **	0.94 **	-0.12

r = correlation co-efficient.

X = ambient temperature within range 70° - 105°F.

RT = rectal temperature.

RR = respiration rate.

PR = pulse rate.

** = highly significant ($P < 0.01$) .

SECTION IV

Water Consumption (W) (Reference Figure 6 and Appendix Table 6).

Feed Consumption (F) (Reference Figure 6 and Appendix Table 7).

Consumption of water (gallons) and feed (lb.) are expressed as average daily values during exposure to different ambient temperature conditions. During each trial, water and feed were always available ad libitum.

WATER INTAKE

Water consumption materially increased with temperature rise and with one exception maximum intake coincided with peak thermal exposure. The differential behaviour of Cow A2 may be related physiologically to the greater reduction in milk yield which did occur at 95° - 105°F.

Drinking habit was greatly influenced at stress temperatures; frequency of visits to the water troughs increased and prolonged cooling and washing of the tongue and nostrils were common to all cows.

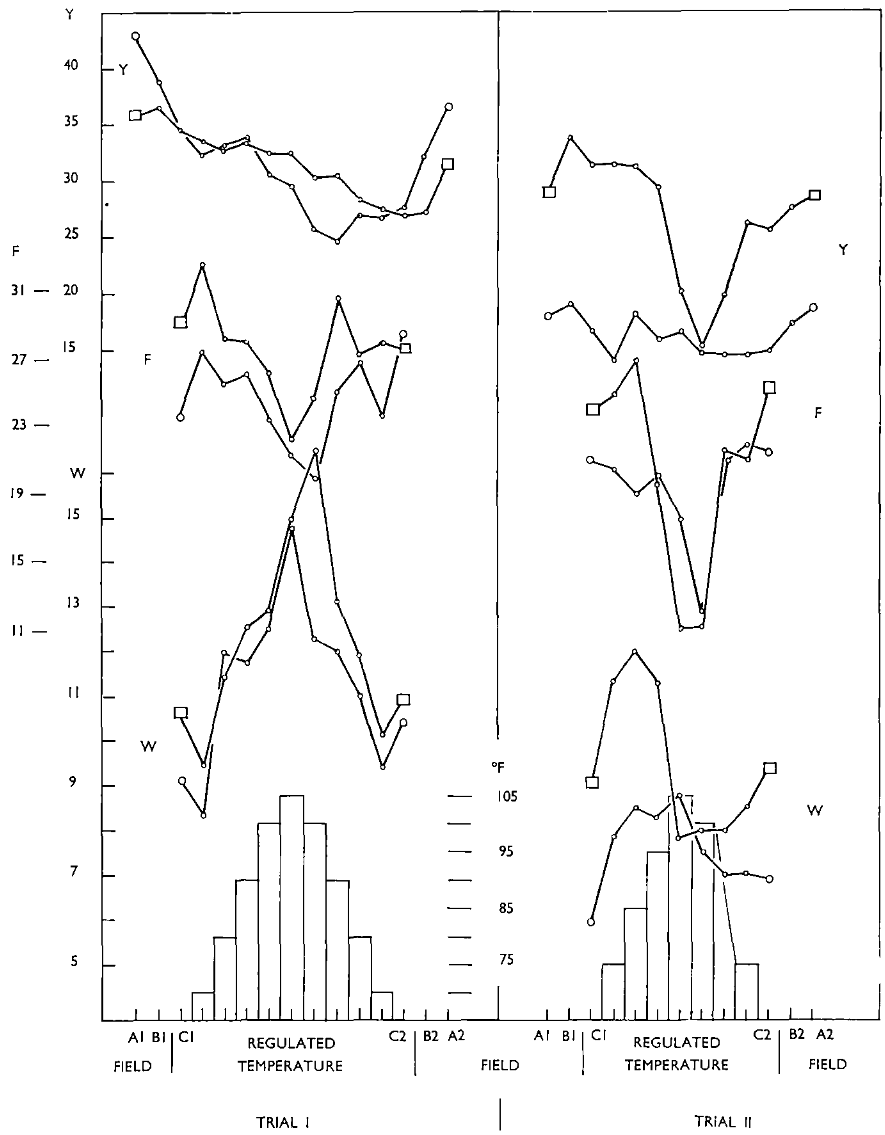
FEED INTAKE

Irrespective of feed treatment, intake was generally maintained over the temperature range 70° - 80°F but exposure above 80° - 85°F was associated with material loss of appetite.

Feed and water consumption returned to normal levels in the final Control Periods.

FIGURE 6

Effect of Air-Temperature on Yield of Milk in lbs. (Y); Feed Consumption in lbs. (F) and Water Consumption in gallons (W). (Values are daily averages for each Temperature of exposure) Legend and Feed Treatment - as per Figure 1.



SECTION V

Miscellaneous

(a) Body Weight - All animals were weighed one hour post the a.m. milking, which marked the commencement (housing of stock) and termination (transference of stock to field) of each Trial.

Weight recordings are presented as follows :

TABLE 7

Trial	Cow	Weight (lb.) In	Out	Loss lb.	% Weight Loss
I	A1	782.7	758.6	24.1	3.0
	B1	862.2	776.1	86.1	10.0
II	A2	718.8	707.8	11.0	1.5
	B2	734.1	714.4	19.7	2.7

Though the data indicates that final loss of condition did occur, body weight decreases of the order of 1% to 3% are not regarded as substantial when considered in relation to the severity and time of thermal stress conditions to which the cows were subjected. However, the immediate influence of stress temperature may be somewhat masked by partial animal recovery during temperature decline to control levels. Animal appearance, general tone, appetite and performance materially improved in this period.

The greater and comparative weight loss of cows B1 and B2 on the diet of low protein concentrate plus chaff may be of some significance.

(b) Faecal Texture. An additional index of physiological upset in animal metabolism, at elevated temperatures in excess of 95°F, was provided by the change in faecal texture. Though on dry feed, there was a marked tendency for faecal material to become loose and watery, and this was most noticeable in cows which showed greatest intolerance to thermal stress, as measured by increase in body temperature and respiration rate. This condition was associated with maximum water consumption and reduced feed intake, but rapidly returned to normal with temperature decline.

(c) Visual evidence of distress and nervous tension at elevated temperatures greater than 95°F was associated with restlessness, accelerated respiration akin to panting, tongue protrusion, profuse salivation, sliming of nostrils, prolonged periods of breathing over the surface of water troughs, &c., and was most prevalent in cows which experienced greater body temperature increase.

There was a general absence of sweating, but when recorded, this was only very slight and mainly located under the upper forearms and between the udder and hind legs. At high temperatures, slight sweating in the vicinity of the nostrils, occurred with Cow B1 in Trial I.

(d) The cycle of rumination appeared to be uninfluenced by ambient temperature increase. Rumenal movements were normal, with only occasional and very slight variation from the uniform rate of two rumen movements per minute. Cow A2 showed greatest tendency in this respect.

PART II

THE INFLUENCE OF ALTERNATING DAY AND NIGHT AMBIENT AIR-TEMPERATURE

Trials I and II were concerned with the fundamental influence of constant ambient temperature on milk composition and equilibrium. Exposure at constant temperature levels does not obtain in the summer field environment where differences of the order of 20°F or greater obtain between daily maximum and minimum shade temperatures. Trials III and IV were conducted to simulate operation of diurnal temperature variation.

Experimental Procedure

The original experimental Cow Groups A and B were retained and the following modifications effected in general design and procedure.

DIURNAL TEMPERATURE VARIATION

Ambient temperature adjustments were made at 9.00 a.m. (one hour after the a.m. milking) and at 4.00 p.m. (one hour before the p.m. milking). Day temperatures were maintained for a period of approximately 5½ hours (10.30 a.m. to 4.00 p.m.) and night temperatures for 15½ hours. Day and night temperature adjustments in each case were effected over a period of 1½ hours.

The pattern of day and night temperature variation and duration of exposure (days) for each temperature combination were as follows:

TABLE 8

Trial No.	Cow	Trial Ration	Initial Control Period Ambient Temp. 51^{o}-$62^{o}F$	Temperature $^{o}F \pm 2^{o}F$ (Day/Night)							Final Control Period Ambient Temp. 51^{o}-$62^{o}F$
				75/ 75	85/ 85	90/ 75	100/ 75	100/ 85	95/ 85	100/ 85	
III	A1 B1	Y)) X)	4	2		5	2	7			4- Days
IV	A2 B2	Y)) X)	8 *	2	2				2	5	4- Days

* Initial control period (C1) Trial IV extended to 8 days, due to initial digestive upset of Cow A2 during final conversion to Trial Ration.

Feed Treatments were reversed as shown in Table 8.

Physiological Measurements

Body temperature (R.T.), respiration rate (R.R.), pulse rate (P.R.) and rumenal movement were recorded twice daily, viz. 9.00 a.m. and 4.00 p.m. readings, immediately prior to temperature adjustments, corresponding to $15\frac{1}{2}$ hours and $5\frac{1}{2}$ hours exposure to night and day air-temperatures respectively.

Under conditions of constant air-temperature, all measurements were 9.00 a.m. readings.

Elimination of Oestrus Cycle

Whereas in Trials I and II non-pregnant cows were utilised, cows were artificially inseminated before the commencement of Trials III and IV and with the exception of Cow A1 conception established prior to cow utilisation. In mid-late summer normal herd management ensures that most cows are in various stages of gestation (late-winter, early-spring and autumn calving). Trials III and IV aimed to simulate this field practice.

Animal Health

There was no evidence of mastitis or of udder abnormality.

Results

SECTION I

Solids not Fat (S.N.F.) (Reference Figures 7 and 8; Appendix Tables 8-11 incl.)

Freezing Point Depression (Δ) (Reference Figures 7 and 8; Appendix Tables 8-11 incl.)

Inherent Acidity (A) (Reference Figures 7 and 8; Appendix Tables 8-11 incl.)

The effect of feed treatment, prior to temperature regulation, was more marked than in Trials I and II. The less favourable ration Y effected a marked decrease in S.N.F., Δ and acidity test levels. Ration X, balanced for milk production, maintained or increased test levels.

Exposure to constant air-temperatures of 75° and 85°F did not materially influence rectal temperatures and were again associated with either strong stabilisation or increase of test values. An exception was Cow A2 which, as previously reported, suffered from a digestive disorder during the initial control period (C1). This necessitated a delay in application of temperature regulation until normal feeding, production and composition levels were re-established.

Such disorder may have had some bearing on the prolonged S.N.F. decrease recorded and the apparent absence of definite differentiation between feed and temperature effects.

The subsequent pattern of S.N.F., Δ and acidity behaviour appears to be strongly influenced by the capacity of the cow to maintain a relatively constant body temperature, which is depicted in Figures 7 and 8 in conjunction with body temperature measurements.

The R.T. recordings provide the point in time and day/night temperature combination, when either decrease of test values was initiated or obvious disturbances effected, which could be directly attributed to air-temperature effect. This point occurred when rectal temperature increase was progressive and permanent over the full-day period of differential temperature regulation. The observed day/night temperature combination was $100^{\circ}F/85^{\circ}F$ in Trial III and $95^{\circ}/85^{\circ}F$ in Trial IV. This indicates that, for the arbitrary periods of exposure adopted in this work, a day-temperature exceeding $85^{\circ}F$ and a night temperature greater than $75^{\circ}F$ but near to $85^{\circ}F$, were requisite for change in S.N.F., Δ and acidity. The critical temperature of $85^{\circ}F$ observed, is confirmatory for that established in Trials I and II.

FIGURES 7 and 8

Effect of Alternating Day and Night Air-Temperature on -

1. % Solids-not-Fat (S.N.F.) - Expressed on the Fat-Free-Serum (F.F.S.) basis.
2. Inherent Acidity (A) - Expressed as % lactic acid equivalent.
3. Freezing Point Depression (Δ °C). (Values are weighted daily averages P.M./A.M. production)
4. Rectal Temperatures (R.T. °F) - daily averages; daily recordings during ambient temperature alteration.

R.T. o———o 4.00 P.M. recordings.

R.T. o———o 9.00 A.M. recordings.

Ambient Air-Temperatures °F -

= Maximum day Temperature: $5\frac{1}{2}$ hrs. exposure (10.30 A.M. - 4.00 P.M.)

= Minimum night Temperature: $15\frac{1}{2}$ hrs. exposure (5.30 P.M. - 9.00 A.M.)

Legend - as per Figure 1.

FIGURE 7

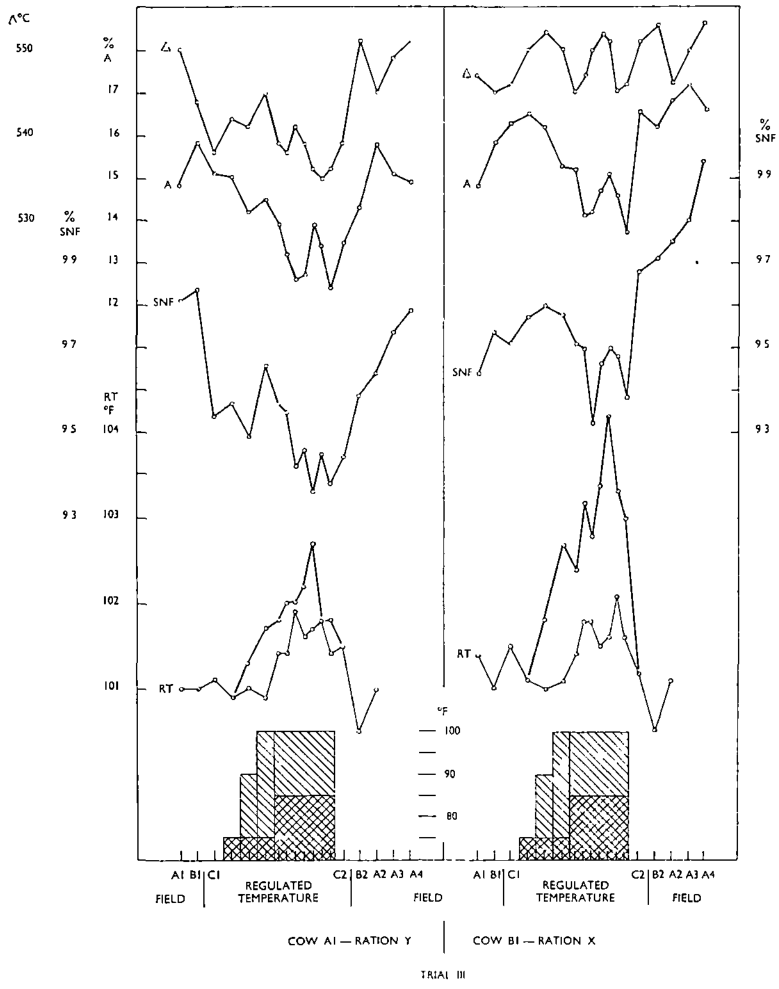
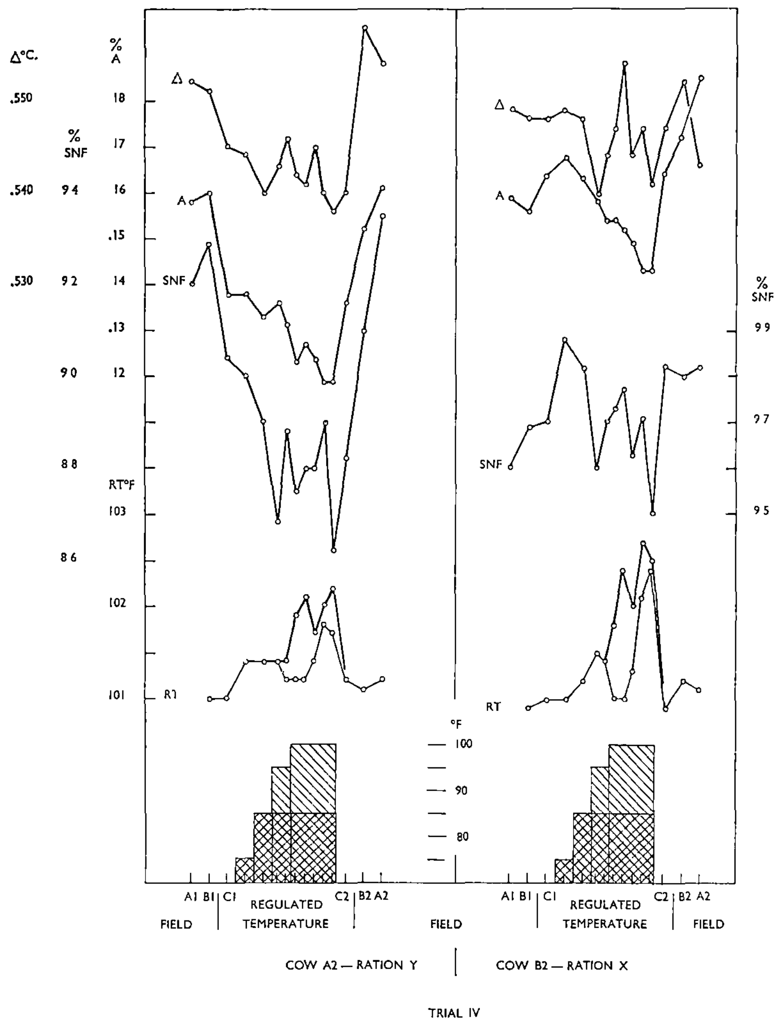

Δ°C
550
540
530
%
Δ
17
16
15
14
13
12
%
SNF
99
97
95
93
RT
°F
104
103
102
101
Δ
A
SNF
RT
°F
100
90
80
A1 B1 C1
REGULATED
TEMPERATURE
C2 B2 A2 A3 A4
FIELD
FIELD
COW A1 — RATION Y
COW B1 — RATION X
TRIAL III

FIGURE 8



Δ°C.
% A
% SNF
.550
.540
.530
18
17
16
.15
14
.13
12
94
92
90
88
86
RT°F
103
102
101
Δ
A
SNF
RT
% SNF
99
97
95
°F
100
90
80
A1 B1 | C1 REGULATED TEMPERATURE C2 | B2 A2
FIELD
FIELD
COW A2 — RATION Y
COW B2 — RATION X
TRIAL IV

Night temperatures of 75°F ($15\frac{1}{2}$ hours exposure), associated with maximum day temperatures of 100°F ($5\frac{1}{2}$ hours exposure) did not appear to have an immediate effect on test values. The lower non-stress night temperature apparently permitted recovery from the heat stress experienced during the day. This does not, however, rule out the possibility of such an effect occurring, if the period of exposure to similar day/night temperature combination had been materially extended in time, as does occur in the field.

At high air-temperatures and with cows in heat stress, changes in S.N.F. and acidity were similar to but less marked than those in Trials I and II. With Cows B1 and B2 (feed treatment - Ration X), the freezing-point depression did not show a progressive decrease but the fluctuations in Δ values did indicate disturbances in osmotic equilibrium.

Milk composition and equilibrium changes appear to be a function of time of exposure to a critical air-temperature level or equivalent day/night temperature combination, such that body temperature does not recover but progressively increases to "fever" levels.

In the final control period (C2), recovery of depressed test values was complete with cows on Ration X, incomplete with Ration Y but finally attained in the field.

Trials III and IV terminated in the early-spring and late-spring/early-summer respectively, when there was a steady improvement in the thermal comfort zone for cattle and in the qualitative and quantitative character of available pasture. The influence of such a favourable environment is reflected in trend direction, rapidity of change and in the final and higher level of attainment, of S.N.F. and acidity test values (field data A2 to A4 compared to A1). These high test levels were associated with stimulated milk yields. This unique relationship of yield and composition (S.N.F.) increase, originally referred to by Bartlett, et alia (1948), as "the galactopoietic effect of spring grass", is of universal occurrence and shown to be very dominant in the closing stages of these Trials. It was not evident in Trials I and II, which terminated in the winter.

SECTION II

Milk Yield (Reference Figure 9 : Appendix Tables 8-11 incl.)

Fat - Concentration and Production (Reference Figure 9 : Appendix Tables 8-11 incl.)

S.N.F. Production (Reference Figure 9 : Appendix Tables 8-11 incl.)

The effect of exposure to the heat-stress conditions of day, on milk-yield, production of fat and non-fatty milk solids, is shown to be radically variant from the marked depression which obtained for conditions of constant temperature exposure. The maintenance of relatively uniform milk-production levels, is reflected in less variation shown by milk-fat concentration.

FIGURE 9

Effect of Alternating Day and Night Air-Temperature on -

Milk-Yield (lbs.); Fat (%); Yield of Fat and Solids-not-Fat (lbs.). (Values are daily means; weighted for % Fat.)

Feed Treatment -

□ - o - o Trial III - Cow A1; Trial IV - Cow A2; Trial Ration Y

O - o - o Trial III - Cow B1; Trial IV - Cow B2; Trial Ration X

Ambient Air-Temperature ^{o}F -

= Maximum day Temperature: $5\frac{1}{2}$ hrs. exposure

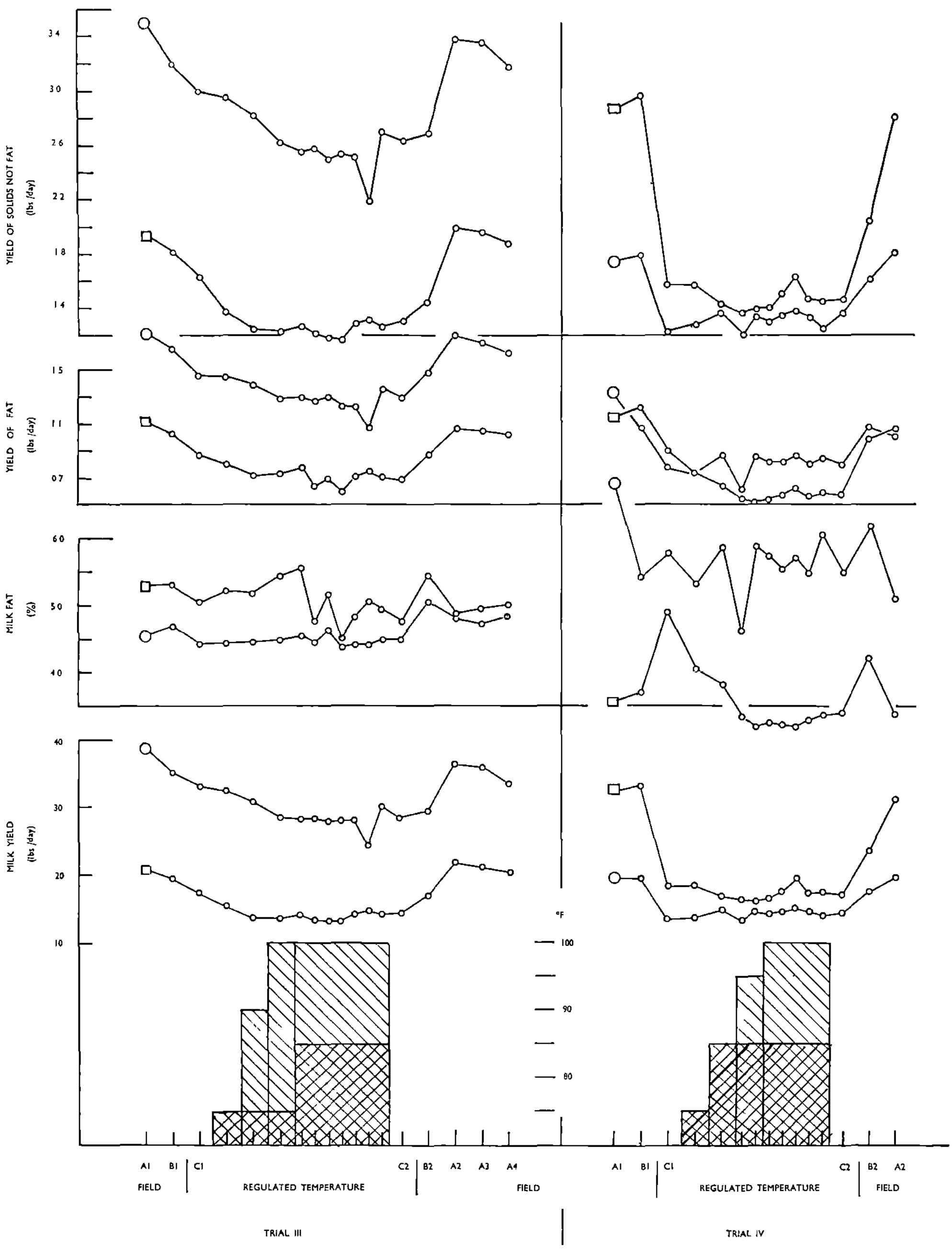
(10.30 A.M. - 4.00 P.M.)

= Minimum night Temperature: $15\frac{1}{2}$ hrs. exposure

(5.30 P.M. - 9.00 A.M.)

Legend - as per Figure 1.

FIGURE 9



YIELD OF SOLIDS NOT FAT
(lbs/day)
YIELD OF FAT
(lbs/day)
MILK FAT
(%)
MILK YIELD
(lbs/day)
°F
100
90
80
A1 B1 C1 C2 B2 A2 A3 A4
FIELD
REGULATED TEMPERATURE
FIELD
A1 B1 C1 C2 B2 A2
REGULATED TEMPERATURE
FIELD
TRIAL III
TRIAL IV

SECTION III

Water Consumption (Reference Figure 10 : Appendix Table 12).

Feed Consumption (Reference Figure 10 : Appendix Table 13).

Consistent with Trials I and II, water consumption increased with air-temperature increase and the maximum water intake was associated with the higher body temperatures. Even so, the animal's attempt to maintain constant body temperature was unsuccessful.

Drastic loss of appetite, as body temperature increased, did not occur. Feed consumption levels were generally maintained from the initial to the final control periods, with evidence of even slight increase during Trial IV.

The relationship of feed-intake to milk-yield is depicted in Figure 10 and such trends are shown to be sympathetic during temperature regulation.

FIGURE 10

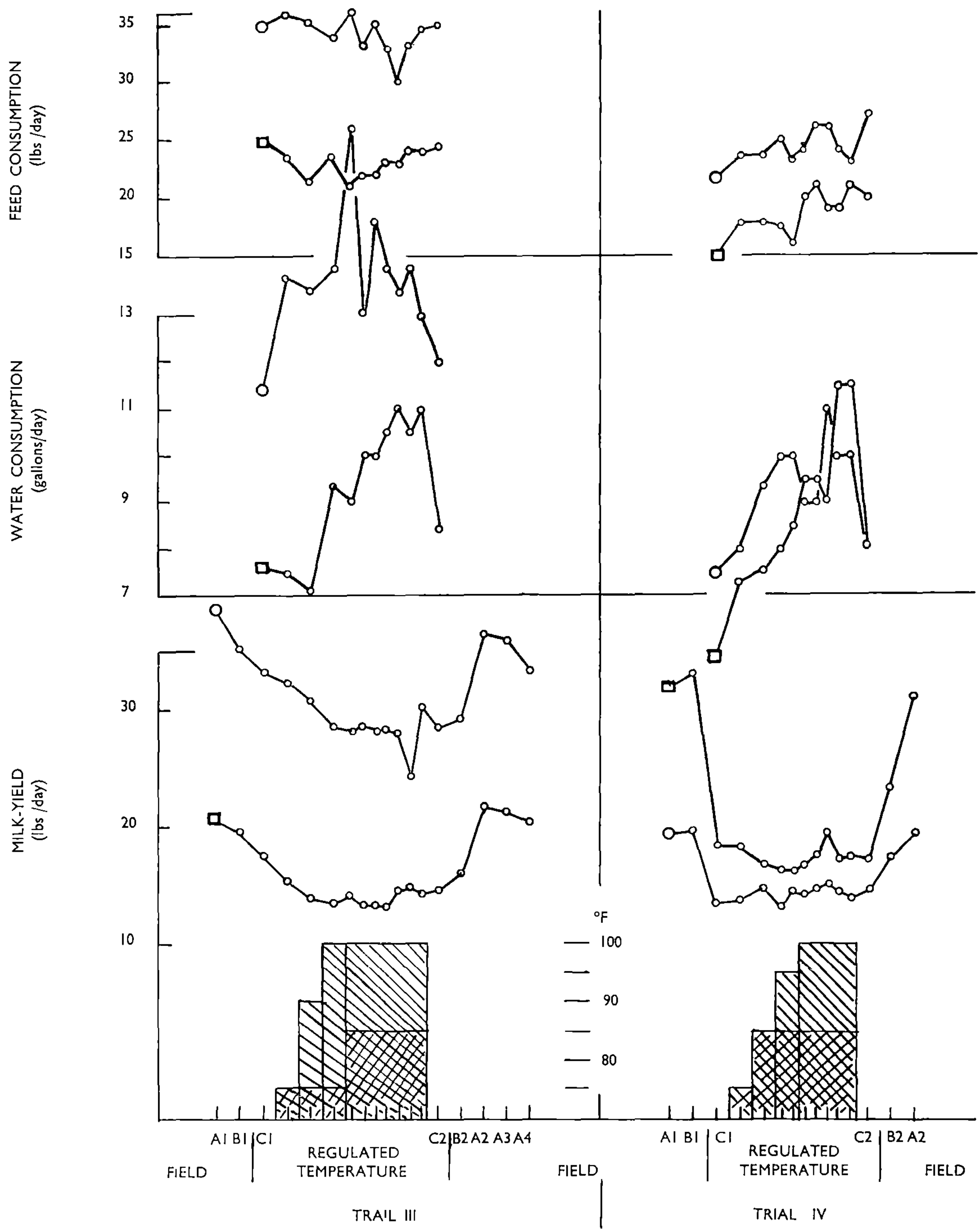
Effect of Alternating Day and Night Air-Temperatures on -

Milk Yield (lbs.); Water Consumption (gals.) and Feed Consumption (lbs.) (Values are daily means).

Feed Treatments and Ambient Air-Temperatures - as per Figure 9.

Legend - as per Figure 1.

FIGURE 10


FEED CONSUMPTION
(lbs /day)
35
30
25
20
15
WATER CONSUMPTION
(gallons/day)
13
11
9
7
MILK-YIELD
(lbs /day)
30
20
10
°F
100
90
80
A1 B1 C1
REGULATED
TEMPERATURE
C2 B2 A2 A3 A4
FIELD
FIELD
A1 B1 C1
REGULATED
TEMPERATURE
C2 B2 A2
FIELD
TRAIL III
TRIAL IV

SECTION IV

Physiological Variables (Reference Appendix Tables 8-11 incl.)

The relationship of R.T., R.R., and P.R. to air-temperature, through the balance of body-heat gains and losses, is again evident and the occurrence and significance of permanent body-temperature increase in relation to S.N.F., acidity and Δ change, is stressed in Section I above.

Final and permanent pulse rate decline did not occur at the higher thermal stress conditions, though, with the exception of Cow A2, the trend towards this condition, was evident.

SECTION V

General -

(a) Body-weight recordings, before and after temperature exposure were as follows :

TABLE 9

Trial	Cow	Body Weight (lb.)		Loss (lb.)	Gain (lb.)	% Weight Loss (-) or Gain (+)
		In	Out			
III	A1	754.1	763.0		8.9	+ 1.2
	B1	767.4	818.1		50.7	+ 6.6
IV	A2	700.1	690.1	10.0		- 1.4
	B2	723.3	764.0		40.7	+ 5.6

(Body-weight recorded 1 hour post the a.m. milking, which marked the commencement (housing of stock) and termination (transference of stock to field) of each Trial).

The above data indicates positive body-weight gain, with the exception of Cow A2. This animal suffered digestive disorder in the initial control period and the very slight weight loss of 1.4% recorded, may be related to the temporary set-back experienced. Within each trial (Cows B1 and B2), the greater body-weight gain was associated with Ration X, the diet of greater nutritional quality. These results are in keeping with the lesser body-weight losses experienced by Cows A1 and A2 in Trials I and II, for the same feed treatment.

PART III

THE INFLUENCE OF BODY FEVER TEMPERATURE

In the post-trial environment B2, Trial IV (regulated change from trial to field feeding), veterinary inspection at 9.00 a.m. and termination of the 6th day (day cycle-day/night : P.M./A.M. milkings) revealed that, whereas the body temperature of Cow A2 was normal, Cow B2 was in a "natural" body fever condition unrelated to direct air-temperature effect. Daily maximum temperatures were not above 70°F.

The condition was diagnosed as being probably related to a slight chill experienced subsequent to removal from the psychrometric room. Within 7 hours (4.00 p.m. reading 7th day), further rectal temperature increase from 103.3°F to 105.0°F had occurred, when 1,500,000 I.U. of penicillin were administered intra-muscularly. The following morning (9.00 a.m. reading 7th day) rectal temperature had returned to normal (100.8°F) and remained constant thereafter (101.0°F).

Appendix Table 14 depicts the effect of this "natural" body fever temperature on the composition, inherent acidity, freezing point depression and yield of milk and physiological measurements R.T., R.R. and P.R. obtaining at the A.M. milk production, P.M. when applicable.

Figure 11 depicts the curve interactions of S.N.F., acidity and Δ trends with rectal temperature rise and fall associated with onset and subsidence of body fever condition.

FIGURE 11

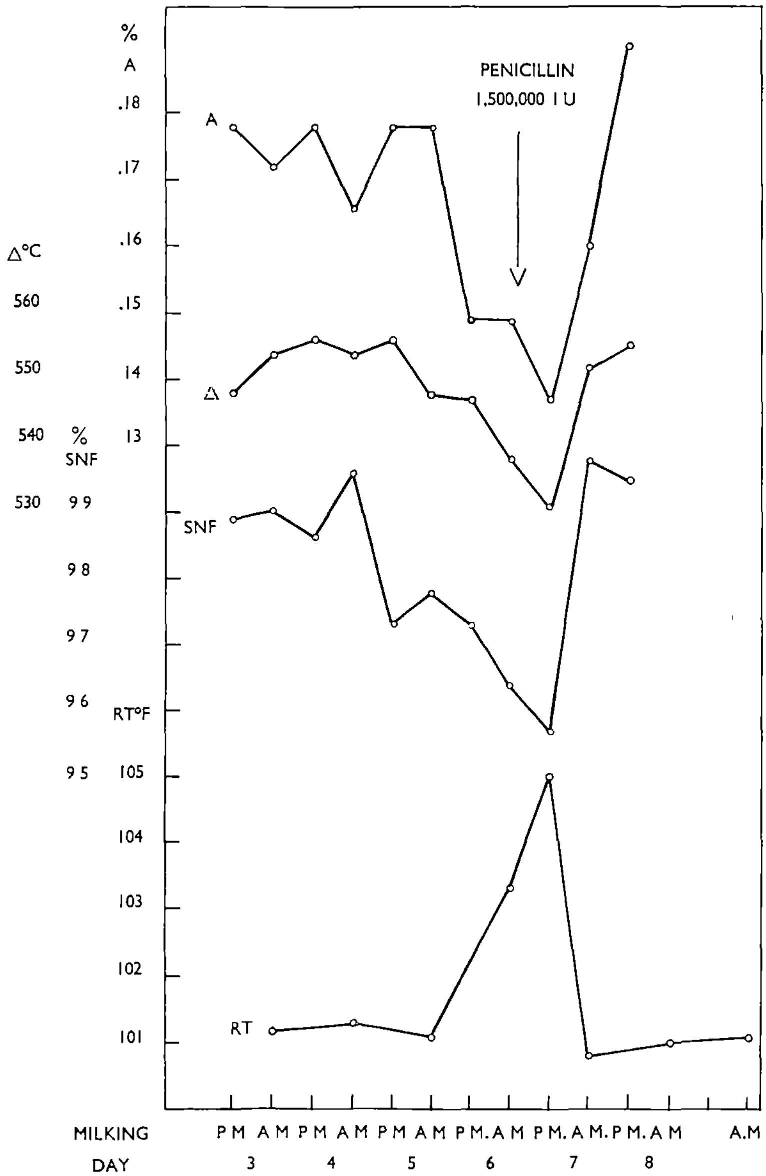
Effect of Body Fever under Field Environmental Conditions on -

1. % Solids-not-Fat (S.N.F. - expressed on Fat-Free-Serum (F.F.S.) basis.
2. Inherent Acidity (A) - expressed as % lactic acid equivalent.
3. Freezing Point Depression (Δ °C).

Values are for consecutive P.M. and A.M. milkings over a 5-day period during which fever occurred.

(Trial IV - Cow B2; Trial Stage B2; 3rd to 8th day).

FIGURE 11



COW B2 TRIAL IV — FIELD ENVIRONMENT B2

Their consideration reveals that :-

1. Decreasing S.N.F., acidity and Δ values were directly related to R.T. increase.
2. The recovery of rectal temperature to normal levels, post administration of penicillin, resulted in immediate re-establishment of normal S.N.F., acidity and Δ test values.
3. Drastic reduction of milk-yield occurred only when rectal temperature was maximum (105°F : milk production 3.7 lb. compared with previous and subsequent P.M. production of 9.3 lb. and 8.5 lb. respectively) as did minimum fat concentration and S.N.F. (F.F.S.).
4. Pulse rate, immediately prior to and during fever condition, was stimulated.
5. Respiration-rate did not however increase and rumenal movement was constant.
6. No index of effect on water or feed consumption was available due to field location of Cow B2, with water and feed available ad libitum.

Thus the effect of "natural" body fever temperature on S.N.F., acidity and Δ was identical to that of body temperature increase induced by heat stress conditions.

6. DISCUSSION

(a) Physiological Responses

(i) Body Temperature and Respiration Rate

Studies in environmental physiology under field and psychrometric room conditions clearly indicate the effect of thermal environment on body temperature and the respiration rate, in addition to providing basic knowledge relating to the thermo-regulatory mechanisms of cattle. (Lee and Phillips 1948; Findlay 1950; McDowell 1958 and Yeck 1959 - reviews of environmental research with dairy cattle).

The dairy cow is a normal warm blooded species or homeotherm and maintains a relative constant body temperature over a wide range of temperature variation. With increase or decrease in ambient air temperature, heat regulating mechanisms are brought into operation which encourage or minimise heat loss and for any thermal level, body temperature represents the balance between heat production, heat absorption and heat loss. Air temperature increase above the zone of thermoneutrality in which biological mechanisms maintain homeostasis, results in body temperature increase, abnormally high body temperatures indicating inefficient thermolysis. The respiration rate is one of the primary mechanisms for maintenance of heat balance, increases with air temperature increase prior to body temperature and is also highly correlated with ambient temperature.

In these Trials, regulated air temperature increase above 70°F severely taxed the homeothermic mechanisms and non-maintenance of essential heat balance resulted in inefficient thermolysis at temperatures above 80°F to 85°F. Body temperature (rectal measurement) rapidly increased with establishment of induced body-fever and changes in milk composition and equilibrium were initiated at this critical thermal level. The respiration rate increased prior to body temperature and their correlation with air temperature (70°F to 105°F) was shown to be highly significant ($P < 0.01$).

Various workers have established this critical hyper-pyrexial level at 85°F and have shown a high correlation between both body temperature and respiration rate with air temperature (70°F to 105°F) with the temperate breeds of dairy cattle. (Hall and Brody 1933; Bartlett 1935; Kleiber and Regan 1935; Regan and Freeborn 1936; Regan and Richardson 1938; Rhoad 1938: 1940: 1944; Gaalaas 1945; Seath and Miller 1946: 1948; Riek and Lee 1948 and Kibler and Brody 1949: 1950: 1951: 1954).

The highly significant correlations ($P < 0.01$) found by Quartermain (1962) and Blaxter and Price (1945) related to much lower temperature ranges (40°F to 80°F and 45.5°F to 62.5°F).

(ii) Pulse Rate

In Trials I and II, the pulse rate increased with temperature increases from 70°F to 90°F and 75°F to 95°F (strong stabilisation with Cow B1 - Trial I) but sharply declined to minimum rates at 95°F to 105°F when rectal temperatures were maximum. Similar pulse stimulation was observed in Trials III and IV (4.00 p.m. readings - higher day temperatures) until the day/night temperature of 100°F/85°F was reached.

The pulse rate then declined when body fever was maximum. The exception was Cow A2 - Trial IV whose heart rate progressively increased.

The literature indicates that when an increase in air temperature causes a change in pulse rate, the result is a decrease. (Regan and Richardson 1938; Kelley and Rupel 1937; Ralston et alia 1940; Bonsma and Pretorius 1943; Kibler and Brody 1949 and Kibler et alia 1949). Brody (1945) confirmed this behaviour and suggested that if temperate cattle were ill-endowed with functional sweat glands, blood would be drawn from the periphery under conditions of external heat stress and pulse rate would decline.

Kleiber and Regan (1935); Ritzman and Benedict (1938); Seath and Miller (1946) and Riek and Lee (1948) found that changes in air temperature had relatively small effect on pulse rate or that the effect was slight and inconsistent.

Findlay (1950) was of the opinion that, in contrast to man, increasing the blood flow and hence thermal conductance through the superficial tissues, may not be a factor of prime importance in thermolysis in cattle.

Blaxter and Price (1945); Kibler, Brody and Worstell (1949) and Kibler and Brody (1949) recorded similar initial increases in the pulse rate at lower temperatures than those observed in this work. Deductions as to cardiac output or general circulatory activity, cannot easily be drawn from the pattern of heart-rate behaviour, though in general an increased pulse rate denotes increased cardiac output. (Lee and Phillips 1948). On this assumption the initial increase in pulse rate may indicate that when air temperature is materially below body temperature, increased blood flow, as in man, does play an important role in heat dissipation in cattle.

Best and Taylor (1950), a standard reference in human physiology, state that rising temperature ultimately increases pulse rate and effects basic adjustments in the blood-vascular system which are important in increasing heat loss. These adjustments are:-

(a) redistribution of blood-dilatation of cutaneous vessels and inversion of blood from internal regions of the body to the surface;

(b) increase in blood volume by dilution with fluids drawn into circulation;

(c) variation in the blood circulation rate, that is, the minute volume or cardiac output per minute.

Cardiac output is a function of pulse rate and stroke volume (output of heart per beat) and hence increased output is achieved by increasing pulse rate and/or the stroke volume. Normally both increases operate in the production of greater cardiac output and maintenance of output is dependent on the adequacy of the venous flow.

The significance of the pronounced change in character of the heart beat when the pulse rate declined (increasing in depth to a full and bounding condition) is not understood, but may be related to change in the stroke volume. It did not persist with temperature reduction to control levels.

Important differences between cows were recorded in the relative emphasis placed on the different physiological responses involved in maintenance of homeostasis and Veterinary opinion indicated that disturbed physiological function was not critical at any stage.

(b) Milk Composition and Equilibrium

Milk composition and equilibrium deterioration initiated when rectal temperature increase was permanent over the full-day period of temperature exposure. Air temperature conditions were:-

Trials I and II - $80^{o}F$ and $85^{o}F$: 24 hour exposure

Trials III and IV - day/night temperatures of $100^{o}F/85^{o}F$ and $95^{o}F/85^{o}F$

which indicate that for the arbitrary periods of exposure, a day temperature exceeding $85^{o}F$ and a night temperature greater than $75^{o}F$ but near to $85^{o}F$ were requisite for decrease in milk composition and change in milk equilibrium.

Maximum depressions of solids-not-fat (S.N.F.) and acidity (A) concentration and freezing point (F.P. ^{o}C) elevation, associated with air temperature increase, are shown in the following tables 10A and 10B for all cows in all Trials.

TABLE 10A

Constant Day/Night Temperature

Cow	Trial	Ration	% S.N.F. (W.M.)	Elevation F.P. °C	% A
A1	I	X	-0.30	+0.022**	-0.033
B1	I	Y	-0.39*	+0.016**	-0.043
A2	II	X	-0.92*	+0.023**	-0.061
B2	II	Y	-0.45*	+0.009***	-0.031

TABLE 10B

Alternating Day/Night Temperature

Cow	Trial	Ration	% S.N.F. (W.M.)	Elevation F.P. °C	% A
A1	III	Y	-0.22	+0.010**	-0.026
B1	III	X	-0.28	+0.007	-0.028
A2	IV	Y	-0.31*	+0.008**	-0.019
B2	IV	X	-0.44	+0.010***	-0.025

* = % S.N.F. depressed below the minimum legal standard of 8.50%.

** = Freezing points elevated above the legal maximum of -0.540°C.

*** = " " " " " " " " " (marginal).

W.M.= Whole milk basis.

This data shows that the effect of temperature increase was similar but of different magnitude and unrelated to major differences in the nutritional quality of the trial rations X and Y. The degree of change was more drastic when stress temperature levels were maintained for 24 hours, cow response to the lesser stress night temperatures resulting in partial recovery of test values. All cows secreted milk which was sub-standard in either solids-not-fat concentration or the freezing point or both and the incidence of sub-standard milk was greater under heat stress conditions of greater intensity and longer duration.

Freezing point and acidity changes were initiated at lower temperature levels than solids-not-fat change and during temperature reduction normal values were re-established without the appreciable lag shown by the solids-not-fat. The best index of change in animal response or adjustment to increase or decrease in environmental temperature was change in milk acidity and the respiration rate while increase or decrease in body temperature provided the best index of respective decrease or increase in efficiency of animal performance.

Variation in the concentration of fat did not conform to the common pattern of solids-not-fat behaviour and showed an inconsistent relationship to variation in milk yield. In Trials I and II progressive decrease in milk production was closely related to decrease in production of fatty and non-fatty solids but not to variation in fat concentration. (Cows A1 and B1 showed a decrease and Cows A2 and B2 an increase).

In Trials III and IV the maintenance of relatively uniform milk production at high temperature levels, is reflected in greater stability of milk solids production and less variation shown by fat concentration. An increase in fat content is indicated at day/night temperatures of 100°/85°F. This differential response in production of milk and milk solids probably reflects the effect of heat stress conditions of less intensity and shorter duration compared to Trials I and II.

Decrease in inherent milk acidity reflects reduction in buffer capacity due to a net reduction in total concentration of the weak anions and indicates that disturbed physiological function effected a decrease in one or more of the principal milk buffers viz. protein, phosphates, citrates, bicarbonates.

The depression of the freezing point of water in milk is directly related to the osmotic pressure which in turn is dependent on the quantitative solution of molecules and ions. Their influence on this additive property of milk is due mainly to the inherent lactose and soluble salt fractions of the solids-not-fat including the chlorides, citrates, phosphates (Coste and Shellbourne 1919; Porcher and Chevallier 1923; Staub 1926; Post 1926 and Rees 1952) with minor contributions from the non-protein nitrogen, colloidal complexes, sulphate and bicarbonate, as the fat has no effect and that of the proteins is negligible or too small for cryoscopic measurement. Decrease in the freezing point depression therefore implies that altered physiological function effected a decrease in one or more of the soluble components of the solids-not-fat.

Thus common decrease in the values for solids-not-fat, acidity and freezing point depression with air temperature increase reflects a very positive disturbance in the osmotic equilibrium and salt balance of milk.

In Trial I, temperature levels and periods of exposure used during temperature increase, were duplicated during temperature reduction and solids-not-fat recovery to control levels was not attained until animal return to the field environment. The duration of exposure to stress temperatures was materially reduced during temperature reduction in Trial II and eliminated in Trials III and IV and solids-not-fat values did recover to normal levels during the final control period. The slight lag in recovery to normal freezing point and acidity levels in Trial I was not evident in the other Trials, normal milk equilibrium being attained in the final control periods.

Increasing the duration of exposure to heat stress temperatures thus apparently influenced the change in milk serum composition (S.N.F.) to a greater degree than disturbance in salt balance and osmotic equilibrium. Any direct influence however, must be considered conjointly with the direct effects of reduced feed intake (temporary under-nutrition) and possibly inefficient conversion of feed while the cows were under extended periods of thermal stress. Best and Taylor (1950) state that in a homeotherm like man in heat stress or exhaustion (when the heat regulating mechanisms are in complete breakdown) hyperthermia may lead to damage of the nervous centres.

Under standard diet and psychrometric room conditions, studies on the effect of temperature increase on solids-not-fat, inherent acidity and the freezing point of milk are rather limited.

Regan and Richardson (1938) recorded a decrease in solids-not-fat and casein. Slight decrease in the freezing point depression and slight increase in pH inferred decrease in the buffering capacity of milk. Such changes were related to animal heat stress and to breakdown in maintenance of heat balance and were associated with anorexia and decline in milk production. Their observations were very similar to those recorded in this work.

Cobble and Herman (1951) and Richardson (1961) both observed significant solids-not-fat decrease within the critical range 85°F to 90°F but the former could not detect any important changes in the freezing point over the temperature range of 40°F to 105°F (there was a slight tendency to decrease) even though substantial changes occurred in the lactose and chloride contents of the milk.

The effect of controlled high temperature diurnal rhythms was investigated by Riek and Lee (1948) who recorded solids-not-fat increase. Merilan and Bower (1957) confirmed this change but stressed that milk composition change occurred rather slowly and hence trends for any specific temperature cycle were modified by the preceding cycle unless a suitable adjustment period was interposed between the different temperature ranges.

Marked depression of milk yield, total phosphorus and magnesium were recorded by Kamal et alia (1961) during alternate exposure to comfort temperature (65°F) and to heat (80°F to 90°F). Salt balance showed a statistically significant decrease at the higher temperature, which indicated a smaller difference between concentration of anions (citrates + phosphates) and cations (calcium + magnesium) in heat than in cold. Only with cows in early lactation did citric acid and total calcium content significantly decline.

These results support the pattern of inherent milk acidity change in this work, for there is inference that decrease in salt balance and milk acidity implies reduction in concentration of the weak anions.

Table 11 shows that within each Trial, the cow with the higher inherent milk production was least able to cope with heat stress as measured by the extent of rectal temperature increase.

Table 11

Relationship of Milk Production Level to Body Temperature Increase (Cows in Heat Stress)

Trial	Cow	Ration	Max. R.T.°C	R.T.°C (C1)	R.T.°C Increase
I	B1*	Y	104.8	101.7	3.1
	A1	X	102.5	101.1	1.4
II	A2*	X	105.4	101.3	4.1
	B2	Y	102.7	100.9	1.8
III	B1*	X	104.2	101.5	2.7
	A1	Y	102.7	101.1	1.6
IV	A2*	Y	102.2	101.0	1.2
	B2*	X	102.7	101.0	1.7

* denotes cow with the higher milk production

R.T.°C = rectal temperature

C1 = control period (unregulated air temperature)

This association of higher milk production and greater body temperature was independent of feed treatment and closely related to greater depression of solids-not-fat and acidity and higher elevation of the freezing point (vide Tables 10A and 10B).

In Trial IV Cow A2 suffered a digestive disorder in the initial Control Period (C1) and milk production was materially reduced to levels only slightly greater than Cow B2 in the same Trial. Rectal temperature increase and changes in milk test values were of similar magnitude and did not reflect the major differences as in Trial II.

The heat increment of mammary gland metabolism in lactating cows is considerable. Brody et alia (1948) and Johnston et alia (1954) estimated that each 1 lb. of fat corrected milk (F.C.M.) produced, increased metabolic heat production by approximately 10 kilo calories of heat per hour. The production of 50 lb. of F.C.M. per day in a 1000 lb. cow with a resting heat production of 500 kilo calories per hour would have the effect of doubling the resting heat load. Johnston (1958) reported that the level of milk production influenced the degree of response of cows to hot conditions, field and climatic chamber studies indicating that highest producing cows tend to have the highest body temperatures.

Thus heat stress on the cow and the problem of heat dissipation at stress temperature levels, would be greater at the higher level of milk production. However the influence of differences in breed and degree of adaptability of the cross-bred experimental cows to temperature change, cannot be disregarded.

(c) Milk Production, Feed Consumption and Body Weight

Change in milk production was directly related to change in feed intake and in Trials I and II anorexia and decreased milk yield were intimately linked under heat stress conditions. Feed intake was maintained during temperature increase to 80°F and milk production levels were stable. Further temperature increase resulted in material loss of appetite and progressive decline in milk production paralleled reduction in feed intake to minimum levels at maximum air temperatures.

In Trials III and IV milk yield and feed intake levels were maintained. It was observed that at day/night temperatures of 100°F/85°F the amount of feed consumed was materially less during the day compared to night though no direct measurements of these differences were made. This indicates that during the higher day temperatures which were comparable to those utilised in Trials I and II, appetite was in fact impaired and that increased feed intake occurred during the lower night temperature (85°F) which in Trials I and II was not associated with anorexia.

These results suggest that the relationship between decreased feed consumption and decreased milk yield is a function of heat stress intensity and/or its duration, which conditions were present in Trials I and II but absent in III and IV.

Feed treatment affected the degree of body weight loss or gain. Smaller body weight losses were recorded for Cows A1 (Trial I) and A2 (Trial II) and greater body gains for Cows B1 (Trial III) and B2 (Trial IV) with Ration X, the diet of greater nutritional value and balanced for milk production.

Psychro-energetic laboratory studies clearly indicate that:

(a) high temperatures ($50^{\circ}F$ to $105^{\circ}F$) depress milk production and feed consumption, that decline of feed intake parallels and reflects decline in milk production and is associated with loss of body weight, and that high humidities accentuate the deleterious effects of high temperature. (Ragsdale et alia 1948, 1949, 1950, 1951, 1953; Lee 1949).

(b) depression of feed intake and milk production coincides with body temperature increase. (Worstell and Brody 1953).

(c) temperatures above the range $80^{\circ}F$ to $85^{\circ}F$ are critical for depression of milk production and feed consumption and body weight decrease. (Ragsdale et alia 1948).

Our results confirmed these findings but that these effects only became manifest when permanent body temperature significantly increased and "high body-fever" was established. (3° to $4^{\circ}F$ increase above normal rectal temperature).

Ragsdale et alia (1948) partitioned the factor causing depression of milk production into:

(a) decrease in feed consumption associated with temperature increase.

(b) increased temperature acting directly on the mechanism which limits milk production.

Mills and Ogle (1939) and Brody (1945) strongly supported the effect of the former factor, the latter affirming that cattle in the extreme post-absorptive condition (no food in the digestive tract) virtually cease milk production. The evidence of Wayman et alia (1962) in their comparison of constant intake with ad libitum feeding, pointed to a direct and indirect influence (through reduced feed intake) of high temperature and they stressed the significant decrease ($P < 0.05$) in efficiency of energy utilisation for milk production at the higher thermal levels.

Ingestion of food increases heat production and the heat increment of feeding, particularly in ruminants is high, accentuated by mammary gland metabolism and influenced by the nature and amount of food consumed which in turn is determined, at least in part, by the organism's ability to dissipate the heat of metabolism - Rubner's specific dynamic action. (Brobeck 1948). The major concern of a body under thermal stress is to react in such a manner as to reduce this stress and thus declines in feed consumption and milk production are considered as homeothermic mechanisms reducing thermal stress associated with feeding and lactation. (Worstell & Brody 1953).

Thyroxine is acknowledged to be essential for maintenance of normal basal metabolic rate and that administration of the thyroid hormone increases milk yield, phosphorus content of milk and body temperature. In dairy cattle, temperature and thyroid activity are related. (McDowell 1958).

Blincoe and Brody (1955) reported increased thyroid activity at low temperatures (17°F) and depression of the thyroid secretion rate by

30 to 65 percent at high air temperatures (95°F) while Johnson (1958) and Kamal et alia (1959) showed that this depression was associated with reduction of normal levels of neuro-endocrine activity by a hot environment.

Johnston (1958) recorded a material decrease in the estimated thyroid secretion rate (P.B.I. levels) of lactating cows during summer. Premachandra (1958) confirmed this seasonal depression and indicated that an increasingly warm environment may be a greater stimulus to a reduction in thyrotropic hormone secretion than would be an increasingly cold environment for increased thyrotropic activity.

Such evidence strongly infers that reduced milk yields recorded in this work may also be partly related to reduced thyroid activity of cows in heat stress and if so would indicate reduced thyroid secretion rate to be an integral part of the mechanism which limits milk production.

(d) Water Consumption

The ability of homeotherms to regulate body temperature is largely due to water of the blood and tissue fluids and the thermostatic properties of water (highest specific heat of all substances, high heat conductivity and very high latent heat of evaporation) make it ideal as a heat regulating medium, enhanced by other purely physiological factors.

In this study the physiological need for water to replace losses incurred through such agencies as lung and skin evaporation, urination and defaecation was shown to be very great during active heat dissipation. Salivation and general sweating were observed to be rather limited.

Winchester and Morris (1956) summarised studies relating to the effect of air temperature increase on water requirements by dairy cattle, which indicate that individual cows differ widely in the quantities of water consumed and that water consumption for a given animal remains relatively constant with air temperature increase from 10°F to 50°F but increases at an increasing rate above 50°F.

These findings have general but not strict application in this work. A factor (other than physical regulation of heat loss) likely to affect materially the water consumption rate, would be the altered level of milk production.

In Trials I and II, the milk yield of all cows did differentially decrease at high temperatures and, with one exception (Cow A2), the water consumption rate was maximum at peak temperatures. The increase from and decrease to control levels were in harmony with temperature increase and reduction within the range 70°F to 105°F. The milk yield of Cow A2 drastically reduced by approximately 50 percent when air temperature increased above 95°F and was associated with an immediate decrease in the water consumption rate of 4 gallons per day below the maximum rate recorded. This 33 percent decrease occurred when the animal was under maximum heat stress, the rectal temperatures being the highest recorded for any cow in each of the Trials.

Thus with lactating cows under severe heat stress, decrease in milk production below a critical level (not indicated in this work) may reflect a decrease in water requirement needed for maintenance of heat balance.

(e) General

(i) Most field studies concerned with the direct effects of high temperature on the productivity and performance of temperate breeds of dairy cattle are related to a comparison of seasonal variation with seasonal change in temperature and are such that the important effects of seasonal change in feed cannot be separated from those of temperature.

However, data in the literature reviewed under Section 3, Sub-section II : (ii) do strongly indicate that decline in milk production, composition (butterfat and solids-not-fat) and production of milk solids (fatty and non-fatty) are associated with high summer temperatures, that the summer depression is of world-wide occurrence and intensifies under drought conditions and that these changes are not restricted to tropical and sub-tropical climates.

The co-operative study by the Departments of Agriculture of New Zealand and the Crown Colony of Fiji on "The Direct Effect of Tropical Climate on the Performance of European-type Cattle" which was reported by Hancock and Payne (1955) and Payne and Hancock (1957) is of particular importance as identical twin heifers were used and the influence of seasonal feed eliminated, in the conduct of the investigation. Differences in performance of identical co-twins located in New Zealand and Fiji were shown to be directly influenced by climatic differences in temperature and humidity. Because of unequal response shown by the co-twins in Fiji to the stress of the tropical climate, Hancock and Payne suggested the operation of a genotype-climatic interaction which indicated that individual European-type cattle differ in their reaction and suitability for tropical climates.

Limited data (Buchanan and Lowman 1929; Aschaffenburg and Temple 1941; Aschaffenburg and Veinoglou 1944; Rees 1949:1952 and Tucker 1963) link osmotic disturbances in milk with seasonal temperature change but opinion is divided as to whether higher summer temperatures are directly related to elevation or depression of the freezing point. Under Australian conditions (Rees 1949:1952 and Tucker 1963), elevation of the freezing point during the dry temperate summer (winter rainfall area) was similar to that recorded during the dry tropical winter (summer rainfall area), seasonal periods when average maximum temperatures are of the same order, and pastures commonly dry and static. Thus similar environmental conditions, though differing in season, were associated with elevation of the freezing point.

The effects of temperature and radiation on the grazing habits of dairy cattle are important in explaining increase or decrease in milk production. The seeking of shade and a voluntary reduction in food intake by the cessation of grazing are physical homeothermic mechanisms which ease the burden of heat load put upon the animal (Findlay 1950). Studies on grazing habits (Rhoad, 1938; Bonsma, 1940 and Seath and Miller, 1946), indicate that heat stress induced by exposure to high air temperatures and direct solar radiation is related to restriction of normal grazing performance and that there are striking differences in the heat tolerance of various breeds and between temperate and tropical breeds, grazing times being least in the temperate breeds.

Shade temperatures were used in the psychrometric room but in the normal summer field environment dairy cattle are subjected to

significantly higher non-shade temperatures, the extent of direct exposure to solar radiation being dependent upon the availability of natural or artificial shelter. Radiant energy is of extreme importance in heat gain or loss by cattle, direct exposure greatly intensifying the radiant heat load and reducing the potential for radiation loss. (Kelley and Ittner, 1948; Bond and Ittner, 1954). Brody, et alia (1954) investigated the specific effect of radiation on dairy cattle in a constant air-temperature environment. Simulated solar radiation in the psychro-energetic laboratory accentuated the deleterious effects of high temperature, continuous exposure to a radiation level of 180 B.t.u./hr. ft.^{2} caused decline in milk production at temperatures as low as 70°F and increasing radiation intensity increased the depression of feed consumption and milk production at 70°F and 80°F. There were slight body weight decreases and water intake materially increased.
Rectal temperature increase (3°F) in an 80°F environment was effected by increasing radiation intensity from 5 to 180 B.t.u./hr. ft.^{2}. (Kibler and Brody 1954).

Analogous cow responses were recorded in our Trials but at higher thermal levels.

The influence of air-temperature and solar-radiation on physiological responses of lactating dairy cattle under natural summer weather conditions, were studied by Shrode, Williams and Harris, and their colleagues (1960) and their general conclusions were:-

(a) air-temperature was more important in effecting summer weather stress in cattle;

(b) of other climatic variables investigated, solar-radiation was next in importance;

(c) at extremely high temperatures, changes in solar radiation were less effective in producing variation in physiological measurements than at lower air-temperatures;

(d) directly or indirectly, just before and after the threshold level of heat stress (90°F) is exceeded, solar-radiation was only slightly less important than air-temperature.

Air moisture content was not standardised during temperature variation in the psychrometric room. Relative humidity decreased with temperature increase and R.H. values approximated 36 percent at 100°F. Low moisture content is not a constant feature of summer weather but low wet-bulb temperatures are normally characteristic of hot and dry periods in the field environment.

Seath and Miller (1946), Quazi and Shrode (1954) and Barrada (1957) indicated that under field conditions humidity has little or no effect on body temperature of cattle but studies in control chambers have shown a marked effect. (Riek and Lee 1948; Kibler 1953 and Barrada 1957).

Ragsdale, et alia (1953) recorded that relative-humidity increase below 75°F did not significantly affect physiological reactions but within the temperature range 75°F to 100°F markedly depressed milk production and feed consumption. The lower consumption of water at the high-humidity levels compared to low-humidity levels probably reflected in part lower feed consumption and partly lower moisture vaporization at the higher humidities.

The relative importance of a high wet-bulb temperature in causing more heat stress than a high dry-bulb temperature has been investigated by Bianca (1962). Findings, in terms of rectal temperature response, indicated that the effect of the wet-bulb temperature was about twice as great as that of the dry-bulb temperature in cattle, whereas in man it is almost six times as great, the differences reflecting species differences in the capacity for water evaporation. In cattle, heat dissipation by evaporation of water from the respiratory tract is of prime importance and additional to loss by evaporation from skin surfaces and respiratory evaporation is normally less affected than skin evaporation by a high air-humidity.

Therefore solar-radiation and humidity are climatic factors additional to air temperature which materially contribute to the heat-load and the evidence suggests that in the field environment lower shade-temperatures than those established in these Trials, initiate and sustain milk changes.

Field data (Rees 1952 - literature attached) supports this field effect and depicts the strongly complementary curve interactions of air-temperature with variations in the solids-not-fat and the freezing-point of milk during the mid-late summer environment. (Fig. 18 : p. 48). Reciprocal variation indicates a positive and direct response of the lactating cow to increase in environmental temperature above an indicated thermal level. The quality of available pasture during the same seasonal period was relatively stable (Table 9 : Figure 17 : Plate 3 : p. 43:44:47) and in an "end-growth" condition with minimum protein, ash and fat and maximum crude fibre and carbohydrate content. The thermal level (mean maximum day temperatures) at which depression of solids-not-fat and decrease in the freezing-point depression was initiated, was differential for P.M. and A.M. milk,

viz. P.M. milk - 60° to $65^{\circ}F$

A.M. " - $75^{\circ}F$

and further common decrease to minimum values co-incided with progressive increase of daily maximum and minimum temperatures (weekly means) to $83.2^{\circ}F$ and $60.2^{\circ}F$. These thermal limits are materially lower than those which, under psychrometric room conditions, were associated with initial and progressive alteration in milk composition and equilibrium change. In both the field and psychrometric room studies, osmotic disturbance as indicated by change in inherent milk acidity and the freezing point, preceded change in milk composition. The field study indicated also that during day-time milk elaboration in late summer (P.M. milk), the dairy cow exhibits a greater degree of hyperthermy, as earlier initiation of change occurred in composition and equilibrium with P.M. compared with A.M. milk.

(ii) Factors involved in heat conservation (retention and production) or heat loss are dependent upon the function of vital temperature-regulating nervous centres, differentially located in the hypothalamic portion of the forebrain which govern the activities of the autonomic or involuntary nervous system. This in turn exercises the important function of maintaining the constancy of the fluid environment of the body cells (Best and Taylor, 1950; Dukes, 1947). Such sensitive heat centres are activated by the temperature of the blood and/or by nervous reflexes and impulses from nerve endings located at or near the body surface and which are also sensitive to temperature change (Lee and Phillips, 1948).

Regulation of composition, temperature, quantity and distribution of body fluid is effected by action upon the circulatory, respiratory, digestive, excretory and glandular organs, which strive to maintain a normal and stable internal environment.

The experimental data provides no direct explanation of changes in milk composition or equilibrium. They were related to non-maintenance of essential heat balance and body temperature increase above a critical level for normal physiological function.

The literature reviewed under Section 3 : Sub-Section III indicates that when cattle are under heat stress, physical, chemical and biochemical changes occur in blood which affect its composition and acid-base balance and are related to blood vascular adjustments and altered physiological function.

Blood constituents are the precursors of milk constituents and the osmotic pressure of the milk (as reflected by measurement of the freezing point depression in ^{o}C) of cows under normal conditions of feeding and management is similar to that of blood (Winter 1896; Hortvet 1921 and Wheelock et alia 1965) and shows a constancy similar to that found for blood and other body fluids (Dittmer, 1961). With lactating cows in non-heat stress conditions, Wheelock et alia (1961) recorded that milk is in osmotic equilibrium with the blood flowing through the udder, continuously throughout the period the milk remains within the udder and not only during its formation. Changes in milk composition (casein nitrogen, non-casein nitrogen, lactose, potassium, sodium and chloride contents) which occurred in association with the observed changes in freezing point depression, were consistent with a movement of water into and out of the udder in response to any change in the osmotic pressure of blood.

Blood vascular adjustments which result in material decrease in concentration of blood solids (Best and Taylor, 1950; Dukes, 1947), infer a decrease in the concentration of milk precursors which would be accentuated by reduced feed intake.

Decline in values for CO_2 capacity of blood plasma (Dennis and Harbough 1948; Brody et alia, 1949 and Worstell and Brody 1953) and marked fall in blood inorganic phosphates (Riek and Lee, 1948) would be important in indicating a shift in the acid-base balance of blood towards alkalinity and such changes may, on isotonic grounds, be related to the acid-base changes reflected in decrease of milk acidity when air temperature was increased above $85^{o}F$.

Temperate breeds of dairy cattle exhibit polypnoea or panting when in heat stress and the depth of breathing decreases compared to

that when the cow is in thermal equilibrium with its environment.
Lee and Phillips (1948), McDowell et alia (1953), Johnston et alia (1955) and Brody (1956) have shown that the respiration rate and volume do not increase in the same proportion with air temperature increase and confirm the opinion that high respiration rates may develop a respiratory alkalosis with a decline in the CO_2 combining power of the blood.
Findlay (1950) considers that decrease in depth of respiration normally enables the dairy cow to increase the rate of ventilation without over-ventilating the alveoli which would lead to apnoea or blood alkalosis while Bianca (1958) has suggested that with prolonged exposure to heat stress, cardiac acceleration may result from an increased demand for oxygen by the respiratory muscles and thus prolonged hyper-ventilation, while resulting in some cooling of the body, may place a strain upon the heart as well as adding to the danger of induced alkalosis of the blood through excessive depletion of CO_2. Lee and Phillips (1948) share in this opinion.
Barrada (1957) showed that cattle appear to have the ability to compensate for blood alkalosis, except under severe heat conditions (100°F and humid) through the excretion of alkali by the kidneys.

The above evidence directly associates milk change with blood change but the data relating them is limited and incomplete.

(iii) The improvement shown in animal performance at the higher comfort temperatures (70°F to 85°F) is considered to be due to greater efficiency of feed utilisation and less energy requirement for body heat maintenance and general metabolism. This trend was independent of feed treatment.

The marked milk changes which occurred during the week of controlled conversion (Period B1) from field to trial feeding of Ration Y, were similar to those effected at heat stress temperatures with the feeding of both trial rations. This confirms that drastic alteration in feed quality also influences milk change and indicates that in the spring-summer field environment the effect of change (gradual or rapid) in the qualitative and quantitative character of seasonal feed could either be supplementary or complementary to that of the direct effects of temperature on the dairy cow.

Changes in milk production, composition and acid-base balance of milk effected in Cow B2 (field conditions B2 - Trial IV) due to the occurrence of "natural" body-fever were identical to those associated with body temperature increase induced by air temperature increase. The pulse rate but not the respiration rate was similarly affected. These changes were essentially a function of disturbance in heat balance and not due to the direct effects of feed or of a factor associated with environment.

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9. APPENDIX

TABLE 1

Average Composition and Food Values
Trial Rations and Concentrate Mixtures

Composition (%)

Feed	Dry Matter	Ash	Crude Pro-tein	Crude Carbo-hydrate	Crude Fat	Digestible Nutrients		
						Pro-tein	Fat	Carbo-hydrate
Ration "X"	87.8	5.2	10.8	68.8	3.0	8.66	2.33	45.65
Ration "Y"	87.9	5.5	6.9	72.7	2.8	5.21	2.16	45.95
H.P. Concentrate	88.3	4.3	18.4	61.9	3.7	15.04	3.00	45.07
L.P. Concentrate	89.2	4.4	12.8	68.2	3.8	9.74	3.22	45.50

Food Values

Feed	Gross Digestible Energy per 100 lb.	Starch Equivalent per 100 lb.	Protein Equivalent per 100 lb.	Nutritive Ratio
Ration "X"	61.4	48.9	8.14	1 : 5.9
Ration "Y"	57.3	44.3	4.87	1 : 9.8
H.P. Concentrate	69.7	57.7	14.11	1 : 3.4
L.P. Concentrate	64.2	51.2	8.98	1 : 5.4

Average composition of feeds computed from:
Foods and Feeding, A.C.T. Hewitt, 7th Ed. 1951: Department of Agriculture, Victoria.
Digestible nutrients calculated from compositional values.
Food values calculated from digestible nutrients.

TABLES 2–5 INCLUSIVE

Trials I and II

Effect of Ambient Air-Temperature on:

1. Milk Composition.
   Total Solids (T.S.); Solids-not-Fat (S.N.F.) and Fat (F).
   S.N.F. values expressed on Whole Milk (W.M.) and Fat-free Serum (F.F.S.) basis.
2. Inherent Acidity (A.) — Expressed as % lactic acid equivalent.
3. Freezing Point Depression ($\triangle$°C).
   (1–3. Values are weighted daily averages. P.M./A.M. production)
4. Milk Yield (lbs.) — Daily means.
5. Physiological Variables.
   Rectal Temperature (R.T.°F); Respiration Rate (R.R.) and Pulse Rate (P.R.) — Expressed as daily means.

Legend — Pre- and post-trial conditions.

Psychrometric Room.

C1. Initial Control Period; unregulated temperature.

C2. Final Control Period; unregulated temperature.

Field Environment.

A1. Pre-Trial; routine field feeding.

B1. Pre-Trial; regulated change from field to trial feeding.

B2. Post-Trial, regulated change from trial to field feeding.

A2. Post-Trial;
A3. Post-Trial, routine field feeding.
A4. Post-Trial,

TABLE 2

Trial I.—Cow A1 (Ration X — H.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% °F.	Δ °C.	% A	R.T. °F.	R.R.	P.R.	Weight S.N.F. (lb.)	Weight F. (lb.)
Field—	A1	7	35.90	13.68	9.10	9.54	4.58	0.535	0.140	..	..	..	3.267	1.644
	B1	7	36.53	13.58	9.15	9.57	4.43	0.540	0.139	101.0	34	76	3.343	1.618
Psychrometric Room—	C1	4	34.60	13.91	8.92	9.39	4.99	0.539	0.138	101.1	37	78	3.086	1.727
	70	2	33.60	14.04	8.91	9.39	5.13	0.540	0.151	101.6	40	74	2.994	1.724
	80	2	32.90	13.60	9.09	9.52	4.51	0.541	0 154	101.3	58	80	2.991	1.484
	90	2	33.60	13.81	9.09	9.54	4.72	0.545	0.149	101 8	66	80	3.054	1.586
	100	2	32.50	13.33	8.79	9.21	4.54	0.533	0.140	102 1	106	76	2.857	1.476
	105	2	32.65	13.49	8 87	9.30	4.62	0.527	0.127	102 5	105	70	2.896	1.508
	100	2	30.50	12.84	8.87	9.24	3.97	0.523	0.121	102.4	90	68	2.705	1.211
	90	2	30.75	13.63	8.82	9.27	4 81	0.528	0.127	101.8	84	68	2.712	1.479
	80	2	28.30	13.22	8.92	9.32	4.30	0.531	0.137	101.5	56	69	2.524	1.217
	70	2	27.40	12.88	8.80	9.17	4 08	0.532	0.135	101.1	58	69	2.411	1.118
	C2	4	27.04	13.57	8.92	9.36	4.65	0.538	0.148	101.2	43	65	2.412	1.257
Field—	B2	7	27.18	14.15	8.99	9.48	5.16	0.540	0.133	100.8	36	76	2.443	1.403
	A2	7	31.50	13.59	9.06	9.49	4.53	0 541	0.137	101.0	34	78	2.854	1.427
	A3	7	24.80	14.50	8.93	9 46	5 57	0.536	0.143	..	..	..	2.215	1.381
	A4	7	25.10	14.20	9 05	9.54	5.15	0.543	0.144	..	..	.	2.272	1 297

Table 3

Trial I.—Cow B1 (Ration Y — L.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% °F.	Δ °C.	% A	R.T. °F.	R.R.	P.R.	Weight S N.F. (lb.)	Weight F. (lb.)
Field—	A1	7	42.80	14.87	9.09	9.65	5.78	0.545	0.163	. .	.	. .	3.891	2.474
	B1	7	38.85	14.73	9.18	9.72	5.55	0.552	0.149	101 6	29	81	3.566	2.156
Psychrometric Room—	C1	4	34.48	15.13	8 56	9.16	6 57	0.545	0.138	101.7	32	82	2.952	2.265
	70	2	32 35	14.17	8 52	9.03	5.65	0.534	0 141	102.2	35	80	2.756	1.828
	80	2	33.10	14.25	8 58	9.10	5.67	0.537	0.147	101.9	41	80	2.840	1.877
	90	2	33.65	13.78	8 69	9.16	5.09	0.536	0 138	102.3	66	78	2.924	1.713
	100	2	30.70	13.51	8.46	8.91	5.05	0.535	0.129	102.8	96	76	2.597	1.550
	105	2	29.55	13.23	8.39	8 82	4.84	0.530	0.108	104 8	117	64	2 479	1.430
	100	2	25.80	12.99	8.40	8 80	4.59	0.523	0.104	103.8	104	68	2 167	1 184
	90	2	24.80	12.61	8.30	8.67	4.31	0.529	0 106	102.3	86	65	2.058	1.069
	80	2	26.95	12.59	8.44	8.81	4.15	0.532	0.119	102.1	64	68	2.275	1.118
	70	2	26.90	12.73	8.51	8.88	4.22	0.540	0.123	101.6	46	66	2 289	1.135
	C2	4	27.74	12.65	8.43	8.80	4.22	0.534	0.132	101.6	32	63	2.338	1.171
Field—	B2	7	32.13	13.22	8.44	8.86	4.78	0.545	0.142	100.9	28	76	2.712	1.536
	A2	7	36.70	13.29	8.89	9.30	4 40	0.545	0.146	101.2	25	75	3.263	1.615
	A3	7	38.80	13.58	9.01	9 44	4.57	0.547	0.148	. .	. .		3.496	1.773
	A4	7	34.70	13.89	9.24	9 69	4.65	0.553	0.155	.	.	. .	3.206	1.614

TABLE 4

Trial II.—Cow A2 (Ration X — H.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb)	% T S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% °F.	Δ °C.	% A	R.T. °F.	R.R.	P.R.	Weight S.N.F. (lb.)	Weight F. (lb.)
Field—	A1	7	28.80	12.71	8.74	9.10	3.97	0.538	0.149	—	—	—	2.517	1.143
	B1	7	33.92	12.49	8.70	9.04	3.79	0.544	0.154	101.2	29	68	2.951	1.286
Psychrometric Room—	C1	4	31.16	12.67	8.60	8.96	4.07	0.545	0.151	101.3	28	70	2.680	1.268
	75	2	31.25	12.82	8.75	9.12	4.07	0.554	0.157	101.5	33	77	2.734	1.272
	85	2	31.05	12.76	8.81	9.17	3.95	0.548	0.152	101.6	46	74	2.736	1.227
	95	2	29.55	12.66	8.63	8.99	4 03	0.541	0.132	103.5	116	75	2.550	1.191
	105	2	19.95	13.12	8.17	8.60	4 95	0.539	0.109	105.4	139	67	1.630	0.988
	100	1	15 10	13.05	7 95	8.38	5.10	0.538	0.101	104.0	88	60	1.201	0.770
	100–75	1	19.80	12.09	7.89	8.24	4.20	0.531	0.096	101.6	48	64	1.562	0.832
	75	1	26.30	12 52	7.96	8.34	4.56	0.531	0.124	101.0	37	66	2.094	1.199
	C2	4	25.63	12.24	8.68	9.00	3.56	0.540	0.147	101.4	26	62	2.225	0.912
Field—	B2	7	27.32	12.81	8.72	9.09	4.09	0.547	0.142	100.8	21	65	2.382	1.117
	A2	7	28.70	12.11	8.52	8.84	3.59	0.542	0.143	101.0	20	66	2.445	1.030
	A3	7	30.20	12 56	8.63	8.98	3.93	0.556	0.134	. .	. .	. .	2.606	1.187
	A4	7	32.30	12.44	8.87	9.20	3.57	0.552	0.158	. .	. .	. .	2.865	1.153

TABLE 5

Trial II.—Cow B2 (Ration Y — L.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% F.	Δ °C.	% A	R.T. °F.	R.R.	P.R.	Weight S.N.F (lb.)	Weight F. (lb.)
Field—	A1	7	18.00	16.20	8.77	9.37	6.43	0.544	0.166	..	..	..	1.579	1.157
	B1	7	19.04	14.46	8.95	9.47	5.51	0.544	0.163	100.6	28	61	1.704	1.049
Psychrometric Room—	C1	4	16.60	14.30	8.77	9.28	5.53	0.547	0.155	100.9	30	68	1.456	0.918
	75	2	13.85	14.94	8.79	9.37	6.15	0.547	0.166	101.0	35	70	1.217	0.852
	85	2	18.10	14.94	8.83	9.40	6.11	0.544	0.168	100.8	38	64	1.598	1.106
	95	2	15.85	14.93	8.79	9.37	6.14	0.543	0.156	101.2	58	72	1.393	0.973
	105	2	16.45	14.45	8.64	9.17	5.81	0.539	0.149	102.7	79	72	1.421	0.956
	100	1	15.00	14.21	8.58	9.09	5.63	0.538	0.146	102.0	76	60	1.287	0.845
	100–75	1	14.35	15.23	8.38	9.00	6.85	0.545	0.137	101.6	40	68	1.203	0.983
	75	1	14.35	14.62	8.49	9.04	6.13	0.544	0.144	101.0	28	68	1.218	0.880
	C2	4	14.86	14.43	8.78	9.31	5.65	0.543	0.166	101.2	23	61	1.305	0.840
Field—	B2	7	17.15	14.64	8.84	9.38	5.80	0.544	0.159	100.7	19	58	1.516	0.995
	A2	7	18.60	15.77	9.02	9.67	6.75	0.548	0.164	101.0	23	60	1.678	1.256
	A3	7	19.40	14.51	9.11	9.63	5.40	0.551	0.154	..	..	..	1.767	1.048
	A4	7	19.60	15.77	8.94	9.60	6.83	0.549	0.159	..	..	..	1.752	1.339

TABLE 6

Mean Water Consumption — Gallons per day

Trial I			Trial II		
Temperature °F	Cow A1	Cow B1	Temperature °F	Cow A2	Cow B2
Control Period . .	10.60	9.13	Control Period .. .	9.00	5 90
70	9 40	8 25	75	11.30	7.80
80	11.40	12.00	85	12.00	8.50
90	12 50	11.75	95	11 25	8 25
100	12.90	12.50	105	7.80	8.75
105	15.00	15.00	100	8.00	7 50
100	16.50	12 25	100–75	8.00	7.00
90	13.10	12.00	75	8.50	7.00
80	11 90	11 00	Control Period	9.40	6.88
70	10.13	9.38			
Control Period	10.85	10.40			

TABLE 7

Mean Feed Consumption — lb. per day

Trial I			Trial II		
Temperature °F	Cow A1	Cow B1	Temperature °F	Cow A2	Cow B2
Control Period . ..	29 1	23 6	Control Period . ..	24.0	21 0
70	32.8	27.5	75	25.0	20.5
80	28.3	25.6	85	27.0	19.0
90	28.2	26.2	95	19 5	20 0
100	26.3	23 5	105	11.0	17.5
105	22.3	21.3	100	11.0	12.0
100	24.9	20.0	100–75	21.5	21 0
90	30.8	25.1	75	21.0	22.0
80	27.4	26.9	Control Period	25.3	21.5
70	28.1	23.6			
Control Period	27.6	28.6			

TABLES 8–11 INCLUSIVE

Trials III and IV

Influence of Alternating Day and Night Ambient Air-Temperature on:

1. Milk Composition (%).
   Total Solids (T.S.); Solids-not-Fat (S.N.F.) and Fat (F.).
   S.N.F. values expressed on Whole Milk (W.M.) and Fat-free Serum (F.F.S.) basis.
2. Inherent Acidity (A.) — Expressed as % lactic acid equivalent.
3. Freezing Point Depression ($\triangle$°C).
   (Values for 1–3 are weighted daily averages P.M./A.M. production)
4. Milk Yield (lb.) — Daily means.
5. Production of Solids-not-Fat and Fat (lb.) — Daily means.
6. Physiological Variables.
   Rectal Temperature (R.T.°F); Respiration Rate (R.R.) and Pulse Rate (P.R.) — Expressed as daily averages; daily recordings during ambient temperature alternation.

   * Values = 4.00 p.m. recordings, post $5\frac{1}{2}$ hours exposure at the higher day temperature (10.30 a.m.–4.00 p.m.).

   ** Values = 9.00 a.m. recordings, post $15\frac{1}{2}$ hours' exposure at the lower night temperature (5.30 p m.–9.00 a.m.).

Legend — Pre- and post-trial conditions:

Psychrometric Room:

- C1. Initial Control Period; unregulated temperature.
- C2. Final Control Period; unregulated temperature.

Field Environment:

- A1. Pre-Trial; routine field feeding.
- B1. Pre-Trial; regulated change from field to trial feeding.
- B2 Post-Trial; regulated change from trial to field feeding.
- A2. Post-Trial; } routine field feeding.
- A3. Post-Trial; } routine field feeding.
- A4. Post-Trial; } routine field feeding.

TABLE 8

Trial III — Cow A1 (Ration Y — L.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% F.	Δ°C.	% A	R.T. °F.		R.R.		P.R.		Weight S.N.F. (lb.)	Weight F. (lb.)
Field ..	A1	7	20.90	14.58	9.29	9.81	5.29	0.550	0.148	101 0		..		..		1.942	1.106
	B1	7	19.47	14.63	9.32	9.84	5.31	0.544	0.158	101.0		23		62		1.815	1.034
Psychrometric Room	C1	4	17.46	14.12	9.06	9.54	5.06	0 538	0.151	101.1		28		60		1.582	0.884
	75	2	15.25	14.30	9.07	9.57	5.23	0.542	0 150	100.9		28		57		1.383	0.798
										*	**	*	**	*	**		
	90/75	5	13.90	14.19	9.00	9.49	5.19	0.541	0.142	101.3	101.0	68	38	67	55	1.251	0.721
	100/75	2	13.55	14.60	9.13	9.66	5.47	0.545	0.145	101 7	100.9	94	57	78	59	1.237	0.741
		1st	14.10	14.61	9.04	9.57	5.57	0.539	0.139	101.8	101.4	96	38	71	54	1.275	0.785
		2nd	13.40	13.85	9.10	9.55	4.75	0 538	0.132	102.0	101.4	112	42	65	61	1.219	0.637
		3rd	13.30	14.11	8.93	9.42	5.18	0.541	0.126	102.0	101.9	111	68	71	62	1.188	0.689
	100/85	7 4th	13.10	13.53	9.03	9.46	4.50	0.539	0.127	102.2	101.6	109	65	73	64	1.183	0.590
		5th	14.60	13 75	8.91	9.36	4.84	0.536	0.139	102.7	101.7	126	67	66	61	1.301	0.707
		6th	14.80	14 01	8.97	9.45	5.04	0.535	0.134	101.8	101.8	94	54	62	66	1.328	0.746
		7th	14.30	13.87	8.92	9.38	4.95	0.536	0.124	101.8	101.4	110	62	62	56	1.276	0.708
	C2	4	14.48	13.75	8.99	9.44	4.76	0.539	0.135	101.5		28		63		1.302	0.689
Field ..	B2	5	16 02	14.54	9.07	9 59	5.47	0.551	0.143	100 5		23		60		1.453	0.876
	A2	7	21.80	14.04	9.17	9.64	4.87	0.545	0.158	101.0		..		..		1.999	1.062
	A3	7	21.20	14.22	9.26	9.74	4.96	0.549	0.151	..		..		..		1.963	1.052
	A4	7	20.30	14.30	9.30	9.79	5.00	0.551	0.149	..		..		..		1.888	1.015

TABLE 9

Trial III — Cow B1 (Ration X — H.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T S.	% S.N.F. W.M.	% S.N.F. F.F.S	% F.	△°C.	% A	R T. °F.		R.R.		P.R.		Weight S.N.F. (lb.)	Weight F. (lb.)
Field ..	A1	7	38.80	13.58	9.01	9 44	4 57	0.547	0 148	101.4		..		..		3.496	1.773
	B1	7	35.17	13.78	9.09	9.54	4 69	0.545	0.158	101.0		23		70		3.197	1.650
Psychro-metric Room	C1	4	33.06	13.51	9.09	9.51	4.42	0 546	0 163	101.5		28		75		3.005	1.461
	75	2	32.35	13.61	9.14	9.57	4.47	0.550	0 165	101.1		50		80		2 957	1.446
										*	**	*	**	*	**		
	90/75	5	30 90	13.62	9 17	9.60	4.45	0.552	0.162	101.8	101.0	70	42	85	79	2.834	1.375
	100/75	2	28.60	13.62	9.15	9.58	4.47	0.550	0 153	102.7	101.1	111	41	85	71	2.617	1.278
		1st	28.20	13.64	9 08	9.51	4.56	0.545	0.152	102.4	101.4	98	60	80	68	2.561	1 286
		2nd	28.50	13.54	9.08	9.50	4 46	0.547	0 141	103.2	101.8	115	52	84	70	2.588	1.271
		3rd	28.10	13.52	8 89	9.32	4.63	0.550	0.142	102 8	101.8	105	70	74	71	2.498	1.301
	100/85	7 4th	28.20	13.43	9 04	9.46	4.39	0.552	0.147	103.4	101.5	91	60	74	74	2.549	1.238
		5th	27.90	13.49	9.08	9.50	4.41	0 551	0 151	104.2	101.6	122	68	73	68	2.533	1.230
		6th	24.20	13.47	9.06	9 48	4.41	0 545	0.146	103.3	102.1	106	86	70	72	2.193	1.067
		7th	30 20	13.45	8.96	9.38	4.49	0 546	0.137	103.0	101.6	98	68	73	64	2.706	1.356
	C2	4	28.61	13.74	9.24	9.68	4.50	0 551	0.166	101.2		24		69		2.644	1.288
Field ..	B2	5	29.32	14 27	9.22	9.71	5.05	0.553	0.162	100.5		22		64		2.703	1.481
	A2	7	36 60	14.08	9 28	9.75	4.80	0.546	0 168	101.1		..		..		3.397	1.757
	A3	7	36.00	14.07	9 34	9.80	4.73	0.550	0.172	..		.		.		3.362	1 703
	A4	7	33.50	14.32	9.45	9.94	4.87	0.553	0.166	..		..		..		3.166	1.632

TABLE 10

Trial IV — A2 (Ration Y — L.P. Concentrate + Chaff)

Trial Stage	Temp °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S.	% F.	△°C.	% A.	R.T. °F. *	R.T. °F. **	R.R. *	R.R. **	P.R. *	P.R. **	Weight S.N.F (lb.)	Weight F. (lb.)
Field ..	A1	7	32.30	12.44	8 87	9.20	3.57	0.552	0.158	..		..		..		2 865	1.153
	B1	7	33.26	12.66	8.95	9.29	3.71	0.551	0.160	101.0		25		70		2.977	1.234
Psychrometric Room	C1	8	18.29	13.51	8.60	9.04	4.91	0.545	0.138	101 0		19		61		1.573	0.898
	75	2	18 25	12.69	8 64	9.00	4.05	0.544	0 138	101.4		23		53		1.577	0.739
	85	2	16.85	12.39	8.56	8.90	3.83	0.540	0.133	101.4		30		51		1.442	0.645
	95/85	2 1st	16.30	11.76	8.39	8.68	3.37	0.543	0.136	..	101.4	..	29	..	51	1.368	0.549
		2nd	16.10	11.80	8.60	8.88	3.20	0.546	0.131	101.4	101 2	38	30	51	46	1.385	0.515
	100/85	5 1st	16.60	11.72	8.47	8.75	3.25	0.542	0.123	101.9	101.2	76	31	54	53	1.406	0 540
		2nd	17.70	11.74	8.52	8.80	3 22	0.541	0 127	102.1	101.2	64	29	55	54	1.508	0.570
		3rd	19.30	11.72	8.52	8.80	3.20	0.545	0.124	101.7	101.4	66	30	57	52	1.644	0.618
		4th	17 20	11 90	8.61	8.90	3.29	0 540	0.119	102.0	101.8	82	41	55	56	1 481	0.566
		5th	17.40	11 71	8.33	8.62	3.38	0.538	0.119	102 2	101 7	82	55	59	54	1.449	0.588
	C2	4	17.13	11.92	8.52	8.82	3.40	0.540	0.136	101.2		20		51		1.460	0.582
Field ..	B2	5	23.54	12.94	8.72	9.10	4.22	0.558	0.152	101.1		22		67		2.053	0.993
	A2	7	31.20	12.41	9.03	9.35	3.38	0.554	0.161	101.2		..		..		2.817	1.055

Table 11

Trial IV — Cow B2 (Ration X — H.P. Concentrate + Chaff)

Trial Stage	Temp. °F.	Days	Yield (lb.)	% T.S.	% S.N.F. W.M.	% S.N.F. F.F.S	% F.	Δ°C	% A.	R.T. °F		R.R.		P.R.		Weight S.N.F. (lb.)	Weight F. (lb.)
Field	A1	7	19.60	15 77	8.94	9 60	6.83	0.549	0.159	..		..		..		1.752	1.339
	B1	7	19.69	14.59	9.16	9.69	5.43	0.548	0.156	100 9		23		66		1.804	1.069
Psychro-metric Room	C1	8	13.50	14 92	9 14	9.70	5 78	0 548	0.164	101.0		26		61		1.234	0.780
	75	2	13 65	14.66	9 36	9.88	5.30	0 549	0.168	101.0		29		68		1.278	0.724
	85	2	14.85	15.10	9.25	9 82	5.85	0.548	0.163	101.2		39		70		1.374	0 869
										*	**	*	**	*	**		
	95/85	2 1st	13.20	13 79	9.16	9.60	4.63	0 539	0 158	.	101.5	..	42	..	72	1.209	0.611
		2nd	14.70	15.01	9.13	9.70	5 88	0.544	0 154	101.4	101 4	62	38	74	74	1.342	0.864
		1st	14.20	14.88	9 17	9.73	5.71	0.547	0.154	101 8	101 0	84	28	74	70	1.302	0.811
		2nd	14.70	14.75	9.23	9.77	5.52	0.554	0.152	102.4	101.0	74	25	78	73	1.357	0.811
	100/85	5 3rd	15.20	14.81	9.08	9.63	5.73	0.544	0 149	102.0	101.3	64	50	78	80	1.380	0 871
		4th	14.60	14.66	9 18	9.71	5.48	0.547	0.143	102.7	102.1	81	74	82	79	1.340	0.800
		5th	14 00	14 99	8.92	9.50	6.07	0.541	0.143	102.5	102 4	83	78	66	72	1.249	0.850
	C2	4	14.50	14.76	9 28	9.82	5.48	0.547	0.164	100.9		23		66		1.346	0.795
Field	B2	5	17.46	15.37	9.19	9.80	6.18	0.552	0.172	101.2		22		74		1.605	1.079
	A2	7	19.55	14.42	9.32	9.82	5.10	0.543	0.185	101.1		..		..		1.822	0.997

TABLE 12

Mean Water Consumption — Gallons per day

Trial III

Temperature °F	Days	Cow A1	Cow B1
Control Period ..	4	7.6	11.4
75	2	7.5	13.8
90/75	5	7.1	13.5
100/75	2	9.3	14 0
	1st	9.0	17 0
	2nd	10 0	13 0
	3rd	10.0	15.0
100/85 .. .	7 4th	10.5	14.0
	5th	11.0	13.5
	6th	10 5	14 0
	7th	11.0	13.0
Control Period ..	4	8 4	12.1

Trial IV

Temperature °F	Days	Cow A2	Cow B2
Control Period ..	8	5.7	7.5
75	2	7.3	8.0
85	2	7.5	9.3
95/85	2 1st	8.0	10.0
	2nd	8.5	10.0
	1st	9.5	9.0
	2nd	9 5	9.0
100/85	5 3rd	9.0	11.0
	4th	11.5	10.0
	5th	11.5	10.0
Control Period ..	4	8 1	8.0

TABLE 13

Mean Feed Consumption — Lb. per day

Trial III			
Temperature °F	Days	Cow A1	Cow B1
Control Period	4	24.8	34 8
75	2	23 5	36.0
95/75	5	21.4	35.2
100/75	2	23.5	33 8
	1st	21 0	36.0
	2nd	22.0	33 0
	3rd	22.0	35.0
100/85	7 4th	23 0	33.0
	5th	23.0	30.0
	6th	24 0	33.0
	7th	24.0	34 5
Control Period	4	24 3	34.8

Trial IV			
Temperature °F	Days	Cow A2	Cow B2
Control Period	8	15.2	21.7
75	2	17.8	23.5
85	2	17.8	23.5
95/85	2 1st	17.5	25.0
	2nd	16.0	23.0
	1st	20.0	24.0
	2nd	21 0	26.0
100/85	5 3rd	19.0	26.0
	4th	19.0	24.0
	5th	21.0	23.0
Control Period	4	19 8	26.9

TABLE 14

Trial IV — Cow B2 — Field Environment B2

		P.M. Milk							A.M. Milk									
Trial Stage	Day	Yield (lb.)	% T S.	% S N F. W M.	% S N F. F.F.S.	% F.	Δ°C.	% A.	Yield (lb)	% T.S.	% S N.F W.M.	% S N.F F F.S.	% F.	Δ°C.	% A.	R T. °F.	R.R	P.R
Field B2 .	3	7.1	16.51	9.16	9.89	7.35	0.548	0.178	10.4	14.58	9.38	9.90	5.20	0.554	0 172	101 2	25	74
	4	6.8	15.90	9 20	9.86	6.70	0.556	0.178	12.3	15.50	9.35	9 96	6.15	0.554	0.166	101.3	21	74
	5	7 3	16.55	9.00	9.73	7.55	0.556	0.178	10 7	14 38	9.28	9.78	5.10	0.548	0 178	101.1	19	79
	6	9.3	16.32	9 02	9.73	7.30	0.547	0 149	10.8	14.61	9.11	9.64	5.50	0 538	0.149	103.3	22	82
	** 7	3 7	14.45	9 05	9.57	5.40	0.531	0.137	11.0	14 98	9.43	9.98	5.55	0.552	0 160	** 105.0 100 8	27	72
	8	8.5	15.80	9.30	9.95	6.50	0.555	0.190	..	..	..	..	..	..	..	101.0	..	..

R.T., P.R., R.R. measurements 9.00 a m. recordings.

R.T. °F** = 4.00 p.m. recording 7th day; intra-muscular injection of 1,500,000 units of penicillin administered
Effect of Body Fever:

1. Milk Composition Total Solids (T.S.): Solids-not-Fat (S.N.F.) and Fat (F.). S N.F. values expressed on whole milk (W M) and Fat-free Serum (F.F.S.) basis.
2. Inherent Acidity (A.) — Expressed as % lactic acid equivalent.
3. Freezing Point Depression (Δ°C.).
4. Milk Yield.

Values are for consecutive p.m. and a.m. milkings over a 5-day period (Trial IV: Cow B2: Trial Stage B2 — 3rd to 8th day) during which fever occurred

A STUDY OF THE MECHANISM OF SOLIDS NOT FAT AND FREEZING POINT VARIATION WITH PROGRESSION OF THE LACTATION PERIOD OF THE DAIRY COW

by

H. V. REES, B.Sc.Agr.

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INTRODUCTION

In work previously reported, dealing with the seasonal variation in Solids not Fat and Freezing Point values, *Rees* (1947; 1949), observed to occur in bulk market milk, evidence was presented which stressed the need for inquiry into the mechanism of these trends and to determine, if possible, the relative degree of influence of those factors considered directly or indirectly responsible for such variation.

The purpose of this report is to present results of work which has been conducted with this specific objective in view.

* * * * *

PROBLEM APPROACH

It was considered that the initial approach to the problem should be directly concerned with detailed studies associated with the lactation period of the individual cow, selected so as to incorporate adequately the spring and summer seasons characteristic of Tasmania. The individual producing animal is the fundamental unit of the herd and detailed information of such unit behaviour is a basic need in any endeavour to interpret bulk milk change.

This decision was greatly influenced by evidence gained from previous inquiry into change of milk composition with progress of the lactation period during spring and summer (Rees—unpublished data), which indicated, under Tasmanian conditions, a radical departure from the accepted trend behaviour of solids not fat constituents, as commonly found recorded in the literature, e.g., " The S.N.F. tend to decrease slightly up to the first four months then gradually increase to the end of the lactation period ", in a manner analogous to fat variation. This is supported by the work of *Crowther* (1905), *Eckles & Shaw* (1913), *Tocher* (1925), *Drakeley* (1927), *Bartlett* (1934), *Elsdon & Walker* (1942); and by the additional work in relation to the specific behaviour of fat variation of *Hills* (1895), *Crowther & Ruston* (1911), *Ragsdale & Turner* (1922), *Hooper* (1923), *Drakeley & White* (1927), *Becker & Arnold* (1935).

The initial selection of the individual cow made possible the elimination of those variable factors associated with bulk herd milk, which are known to affect the chemical composition of milk so markedly, and the retention for measurement and observation of effect of those which are common to all producing animals.

It was felt that a study of the change of milk composition with progress of lactation, would provide basic data of extreme value in interpreting the mechanism of seasonal changes in bulk market milk previously noted for Tasmanian conditions.

Such an approach facilitated rigid supervision over milk production and records, and ensured that the supply would be uniform and constant with respect to breed influence on the level of milk composition and values of constants; field sampling errors were reduced to an absolute minimum, and throughout the conduct of the work, it was possible to check the milk supply more efficiently by biological methods for evidence of udder infection or abnormality.

By the adoption of a standard routine milking-shed procedure, such influencing factors as time-interval between milkings, cow-bail treatment prior to and during milking, and efficiency and completeness of milk withdrawal, were kept relatively constant throughout the entire lactation period.

Morning and evening milk segregation was deemed advisable, and daily sampling for analyses whenever possible to observe any change of composition (apart from the general seasonal trend) that might be taking place, the result of any drastic alteration in environmental conditions associated with a relatively constant and available source of food supply. This could not be achieved without a relatively continuous picture and record of the chemical composition of the milk being secreted and withdrawn from the udder.

Information as to the effect on milk composition of certain variables only was sought, and by design these variables alone were allowed full play, namely:—(*a*) Changes in seasonal food supply from natural or improved pasture and/or supplementary feeding; (*b*) The primary and secondary effects of climatic factors; (*c*) Stage of lactation.

* * * * *

EXPERIMENTAL PROCEDURE

(*a*) *Selection of the Dairy Animal.*

The experimental animal, Cow "X", was selected partly by the chance of what cows were available, and partly by design as the date on which she was expected to calve approximated closely to the flush feed conditions of spring. Moreover, she was located on an excellent dairying property, well managed in regard to source, type, and seasonal availability of feed, which eliminated the likelihood of the animal suffering from under-nutrition at any stage in her lactation period.

The cow was adjudged typical of the grade herd and selection was in no way influenced by previous production records.

Cow "X."—Grade, Jersey-Shorthorn cross, rising five year; calved 14th July, 1947—normal. Testing commenced 21st July, 1947, from which time the calf was totally removed from the influence of the mother.

Feeding.—The bulk of food intake was associated with selective "all year round" grazing on rich river slopes, sown down to permanent pasture of perennial rye and clovers (subterranean and white dutch). Access to river flats of unimproved pasture, very prone to severe flooding with brackish water, especially during spring, was available and utilised particularly during the summer and autumn seasons. Supplementary feeding was practised throughout the lactation period, morning and evening, at milking time.

Ration.—July-October 1947, 5 lbs. bran; 8 lbs. oaten chaff; November-mid-December 1947, feeding of bran discontinued, oaten chaff retained. The bran concentrate was re-introduced into the supplementary feeding mixture in late December, 1947 (3 lbs. bran + 8 lbs. oaten chaff), increasing to 5 lbs. bran + 8 lbs. oaten chaff, with the advent of late autumn. These quantities were maintained till the end of the lactation.

Lactation Details.—Cow in Season—mid-November and mid-December and was mated to bull—16th December, 1947; lactation ceased 14th July, 1948, animal dried off and in excellent condition; calved 7th October, 1948; milking times during period of lactation, 6 a.m.-5 p.m. $\pm \frac{1}{2}$ hour; hand milked by the same attendant during the complete lactation period.

It is recorded that the feeding programme as practised by the producer was not interfered with, in any respect, during the conduct of the work. Also, within the herd, the experimental animal was milked first.

(*b*) *Milking Procedure and Sampling Method.*

Milking was performed by hand and stripping practised. The yield of freshly drawn uncooled milk was bucket weighed, intimately mixed and 20 fluid oz. samples withdrawn, bottled, and sealed for despatch to the laboratory.

Evening samples were retained in the farm dairy, being water cooled. Morning milk was similarly treated and both samples conveyed to the laboratory within, approximately, two hours of the morning's production, and testing immediately initiated.

Separate daily samples of evening and morning milk were secured on five consecutive days within each week throughout the whole lactation period, commencing with the Sunday evening and ending with the Friday morning production. This procedure was governed primarily by inability to deal with the accumulated week-end samples and by the arrangement of laboratory work generally. Departures from this routine, which occurred on very few occasions, are indicated in the work.

(*c*) *Determinations and Methods.*

Field and laboratory records were obtained in regard to the following points. The chemical methods used are specified—

1. *Yield.*—Expressed as lbs.

2. *Total Solids.*—Gravimetrically. (Analyst 70: 1945: 105.)

3. *Fat.*—Babcock Method. (British Standard Methods—Specification No. 755, Part II, 1937.)

4. *Solids not Fat.*—Calculated by difference.

5. *Freezing Point.*—Hortvet Cryoscopic Method. (Methods of Analysis, A.O.A.C., 5th Ed., 1940, XXII, 26, 27, 28, p. 275.)

6. *Titratable Acidity.*—Dilution 9 ml. milk with an equal volume of distilled water, titrating with standard 0·1N NaOH, using 0·5 ml. phenolphthalein indicator (1% solution in alcohol). Results expressed as percentage of lactic acid.

7. *Lactose.*—

(*a*) *Clarification of Milk.*—Removal of fat and protein effected by acetic acid precipitation. Ten grams milk weighed in tared beaker and washed, with 90 ml. distilled water into 400 ml. beaker. Then 1·5 ml. of 10% CH_3COOH added. Stirred gently. Brought to boil and simmered 2 minutes. Shock cooled in water and placed in refrigerator 1 hour. Filtered by decantation through Whatman No. 1 filter paper into 200 ml. volumetric flask.

Precipitate washed three (3) times with 10 ml. cold distilled water decanting each time on to filter paper and transferring precipitate with last washing. Filter paper + precipitate again washed three (3) times with 10 ml. distilled water, allowing complete drainage after each operation. Filtrate made up to 200 ml. with distilled water and mixed.

Fifty ml. reducing sugar solution contains lactose from 2·5 grams milk.

(*b*) *Sugar Estimation.*—Lactose determined in 50 ml. aliquot of filtrate as directed in Munson and Walker's General Method. (Methods of Analysis—A.O.A.C., 5th Ed., 1940, XXXIV, 37: 38: 39.)

The weight of invert sugar lactose expressed as the monohydrate $C_{12}H_{22}O_{11} + H_2O$ equivalent to obtained weight of Cu_2O was calculated from Munson and Walker's Table. (Ref. Tables XLIII, No. 9, p. 673.)

$$\% \text{ Lactose} = \frac{\text{Equivalent lactose wgt. grms.} \times 100}{2{\cdot}5}$$

8. *Total Chloride.*—The direct method described by *Davies, W.L.* (Analyst 1932: 57: 79) was adopted to avoid loss of chloride by volatilisation that was found by preliminary experiment to occur constantly under the conditions used in the primary ash determination.

9. *Ash.*—According to method outlined in Methods of Analysis, A.O.A.C., 5th Ed., 1940, XXII, 10, p. 270.

Slight trouble was experienced in securing a white ash condition and the following procedure was uniformly adopted. The ash was very slightly remoistened with dil. HNO_3, re-evaporated on a boiling water bath and ignition repeated to constant weight. Heat of ignition and ashing processes were done with a bunsen burner as a regulated muffle furnace was not available. Temperature control was therefore impossible. As volatilisation of chlorides was positively known to be occurring, the residual chlorides were determined in a hot H_2O—ash extraction by titration with $\frac{N}{10}AgNO_3$ using K_2CrO_4 as indicator.

The difference between the found residual chloride of the ash and the total chloride determination was arbitrarily regarded as "loss by chloride volatilisation", expressed as NaCl and such correction added to the found weight of ash. It is freely admitted that the adoption of such an arbitrary compensating correction is open to criticism and strictly not correct, but it is also submitted that the errors involved are very small indeed.

10. *Casein.*—Methods of Analysis. A.O.A.C., 5th Ed., 1940, XXII, 12, p. 270.

11. *Albumin.*—Methods of Analysis. A.O.A.C., 5th Ed., 1940, XXII, 15, p. 271.

Test determinations—total solids, solids not fat, fat, freezing point, titratable acidity, lactose, total chlorides—were conducted on all daily samples secured of both morning and evening milk.

Ash determinations were restricted to a consecutive evening and morning milking, secured at a constant time period within each week of lactation and milk proteins—separate casein and albumin determinations—were determined for a composite sample from the milk samples used in the ash tests.

Further, in order to study the mechanism of S.N.F. variation, the recorded total protein fractions (including non-protein-N) were estimated by difference for those testing periods associated with the ash determinations of separate samples from consecutive evening and morning milkings.

12. *Climatic Measurements*—

(*a*) Daily Maximum and Minimum Temperature;
(*b*) Daily Rainfall;
(*c*) Daily Pressure, at constant time each day; and
(*d*) Occurrence of Frosts.

13. Observations were made on the seasonal condition of pastures and the selective seasonal grazing habit of Cow "X" which secured the bulk of her food intake from grazing. At periods specified in the work, pasture samples were obtained for analysis.

The following standardised procedure was used throughout the work when securing samples. Three widely separate areas, considered representative of pasture condition in regard to growth, severity of grazing, pasture components, &c., were selected, square yard areas pegged out and harvested with a pair of shears. The bulked material was conveyed immediately to the hot room of the laboratory, widely separated to facilitate quick drying and air dried for ten (10) days. The pasture material was then cut into very fine pieces, intimately mixed and preserved for analysis in tightly stoppered bottles.

The following tests were conducted (method references specified) :—

(*a*) Moisture—A.O.A.C., 5th Ed., 1940, XXVII, 2, p. 353.
(*b*) Crude Protein (N × 6·25)—A.O.A.C., 5th Ed., 1940, II, 21, p. 26.
(*c*) Ether Extract of Crude Fat—A.O.A.C., 5th Ed., 1940, XXVII, 21, p. 356.
(*d*) Total Ash—A.O.A.C., 5th Ed., 1940, XXVII, 8, p. 354.
(*e*) Crude Fibre—A.O.A.C., 5th Ed., 1940, XXVII, 25, p. 357.
(*f*) Crude Carbohydrates—Estimated by difference.

14. *Supervision of Animal Health.*—The incidence of udder abnormality was checked throughout the lactation period by:—

(*a*) Weekly microscopic examination of milk smears from consecutive evening and morning bulk quarter samples.
(*b*) Periodic veterinary inspection at approximately monthly intervals for clinical evidence of udder abnormality, and aseptic withdrawal of milk samples from each quarter for detailed microscopic and cultural examination, using the cultural procedure of Edwards (1938).

* * * * *

PRESENTATION OF DATA

It is recorded that for Cow "X" no evidence of the upsetting influence of udder disease could be demonstrated by the technique specified in the methods throughout the lactation period.

Section I.—Results

LACTATION CURVES FOR TOTAL SOLIDS, SOLIDS NOT FAT, FAT AND YIELD.

(See Figs. 1, 2, 3, 4, and 5.)

The change in milk composition following parturition is found to conform to normal expectancy but to be a relatively rapid one. The modification of colostrum flow (of which no sample was secured for analysis although the origins of the lactation curves are strongly indicated) is remarkably regular up to the 3rd and 5th week of lactation with morning and evening milk respectively. The lactation curves during this period for Total Solids (T.S.), Solids not Fat (S.N.F.), and Fat (F.), are strongly sympathetic and in opposition to the rising milk yield curve (see Figs. 1, 2, and 3).

This differential time lag between the dates at which the morning and evening milks commence to exhibit radical and individual alteration in composition, would appear to be of some significance, as it is again strongly in evidence at later stages in the lactation.

It is thus noted that during periods of significant change in milk composition, evening values constantly elevate and depress prior to morning values, irrespective of the extent of trend depression or elevation.

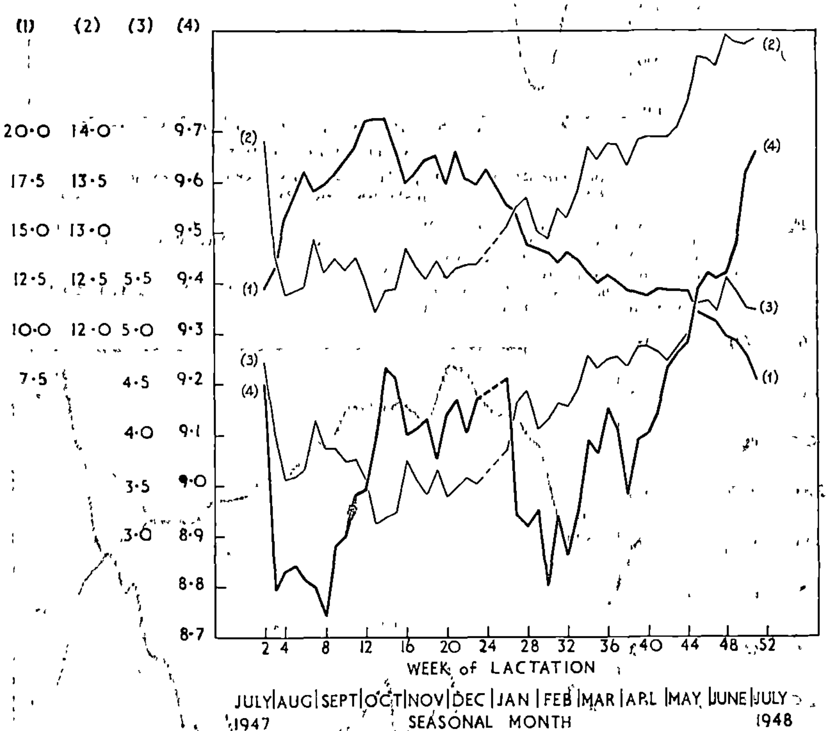

FIG. 1.—Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 237 samples of MORNING MILK taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily yield and composition values of the figures obtained for five consecutive "MORNING MILKINGS" taken in each week of lactation.

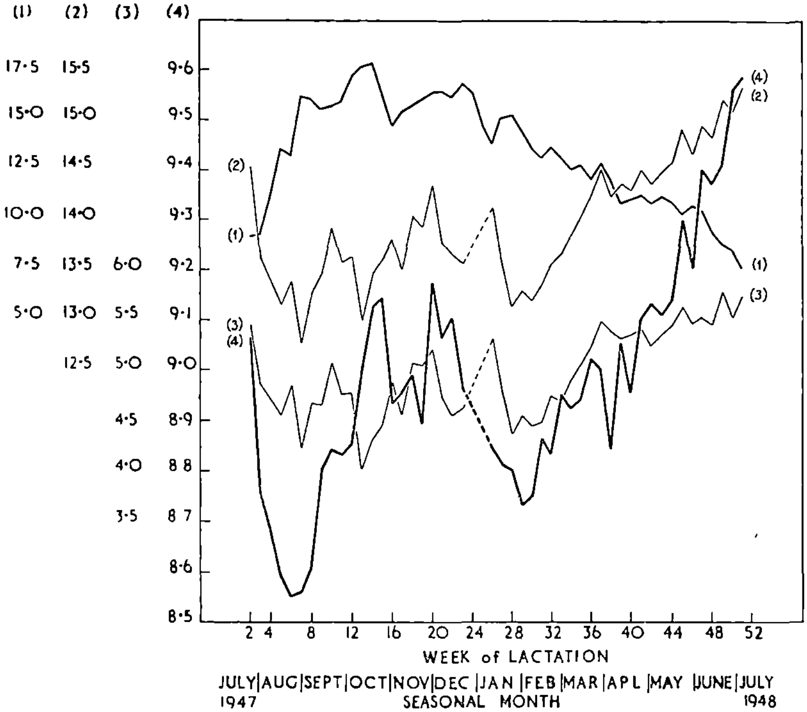

FIG. 2.—Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 237 samples of EVENING MILK taken from Cow "X" during the complete lactation period.
Ordinates of graphs represent the weighted average daily yield and composition values of the figures obtained for five consecutive "EVENING MILKINGS" taken in each week of lactation.

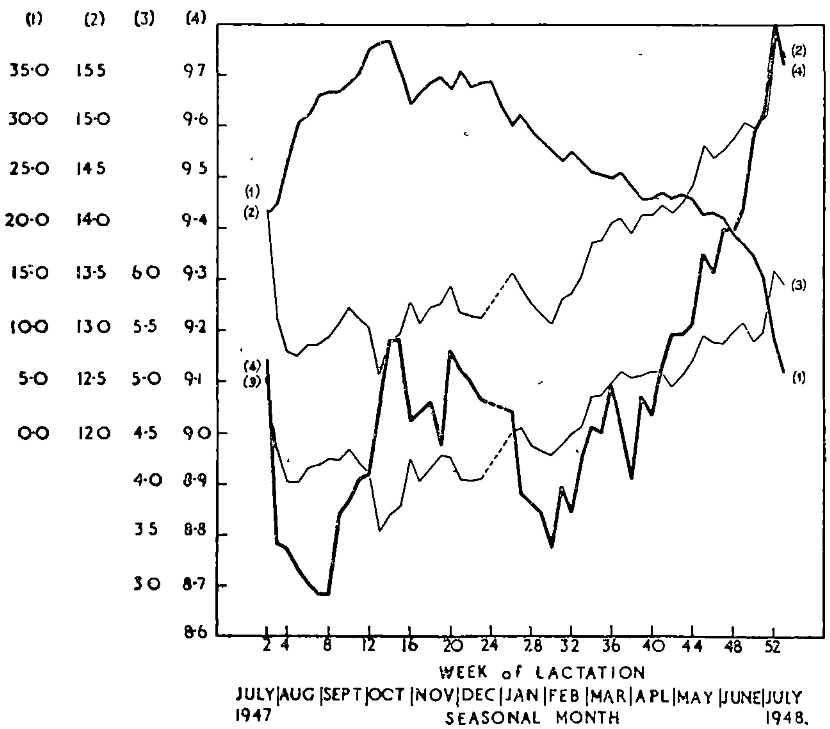

FIG. 3.—Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 245 samples of "BULK MILK" taken from Cow "X" comprising consecutive EVENING and MORNING milkings.
Ordinates of graphs represent the weighted average daily yield and composition values computed from the figures obtained for five consecutive EVENING and MORNING milkings, taken in each week of lactation.

This differential time lag between the dates at which the morning and evening milks commence to exhibit radical and individual alteration in composition, would appear to be of some significance, as it is again strongly in evidence at later stages in the lactation.

It is thus noted that during periods of significant change in milk composition, evening values constantly elevate and depress prior to morning values, irrespective of the extent of trend depression or elevation.

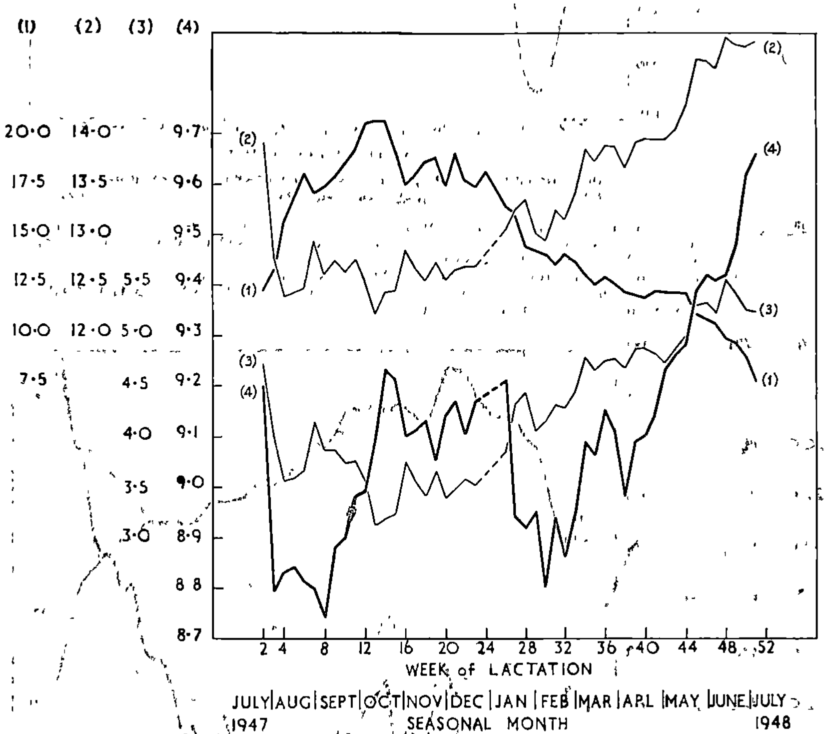

FIG. 1.—Lactation Curves—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 237 samples of MORNING MILK taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily yield and composition values of the figures obtained for five consecutive "MORNING MILKINGS" taken in each week of lactation.

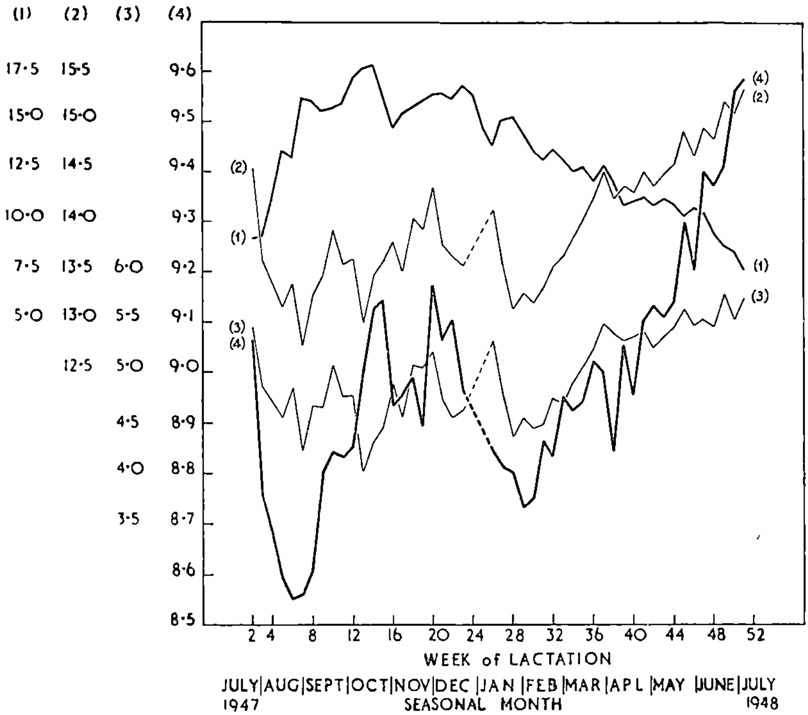

FIG. 2.—Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 237 samples of EVENING MILK taken from Cow "X" during the complete lactation period.
Ordinates of graphs represent the weighted average daily yield and composition values of the figures obtained for five consecutive "EVENING MILKINGS" taken in each week of lactation.

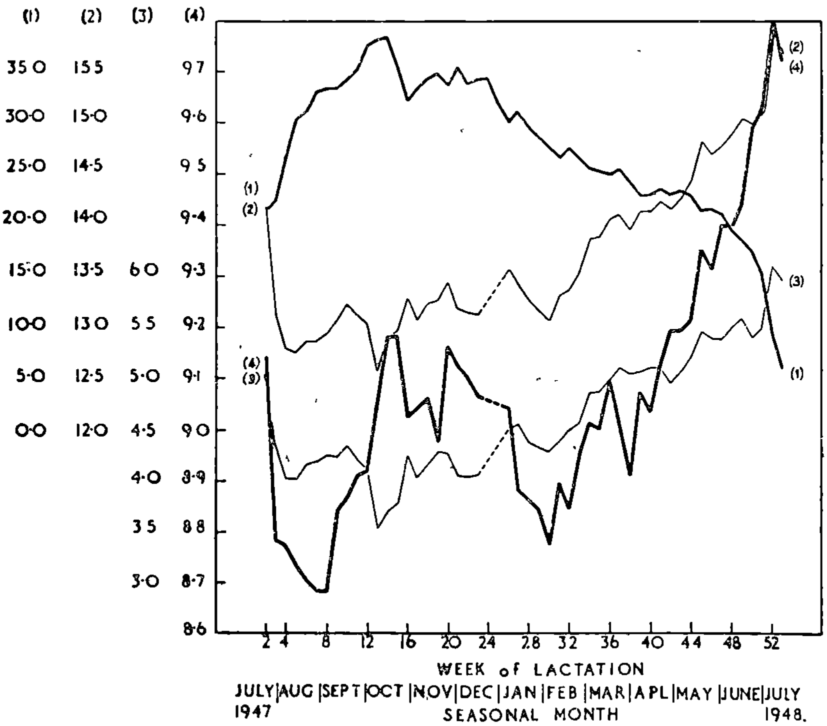

FIG. 3.—Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Total Solids; (3) % Fat; (4) % Solids not Fat—from 245 samples of "BULK MILK" taken from Cow "X" comprising consecutive EVENING and MORNING milkings.
Ordinates of graphs represent the weighted average daily yield and composition values computed from the figures obtained for five consecutive EVENING and MORNING milkings, taken in each week of lactation.

A. Solids not Fat (see Fig. 4).

Post parturition, high values are rapidly depressed, trough figures being attained in August (late winter, corresponding to the 8th and 6th lactation week for morning and evening milk, respectively).

Associated with the spring months of September and October, rapid elevation of both occurred, with initial peak values attained at the same period (14th-15th week) in mid-October. It is observed that the elevated values of morning milk were maintained over a longer period of lactation than those of evening milk—

a.m. milk—14th to 26th week of lactation: mid-October-very early January.

p.m. milk—14th to 20th week of lactation: mid-October-late November.

The depressing lactation curves in late summer are noted to be sharp and steep as occurred during spring elevation and indicative, therefore, of very rapid changes in milk composition, evening values depressing significantly prior to morning. Attainment of common trough values occurred in late summer (early February).

With advance of lactation, values, irrespective of milk type, elevated rapidly and the curves are seen to be relatively parallel.

Throughout lactation the weighted average daily percentage value for each week was higher for morning milk.

Greater depression of evening values is observed associated with those stages when drastic changes in composition level occur, i.e., immediately preceding the trough periods of late winter and late summer. The trends of the values for evening and morning milk are in opposition at such times. The influence responsible must be strong for such trends to be reflected in the weighted average daily figures of graph ordinates.

Outstanding features of the lactation curves are the occurrence of *two* troughs, associated with late winter and late summer and the peculiar behaviour of values associated with the spring and early summer seasons. Evening and morning trends, apart from differences in time periods relating to major elevation and depression, are most similar in character.

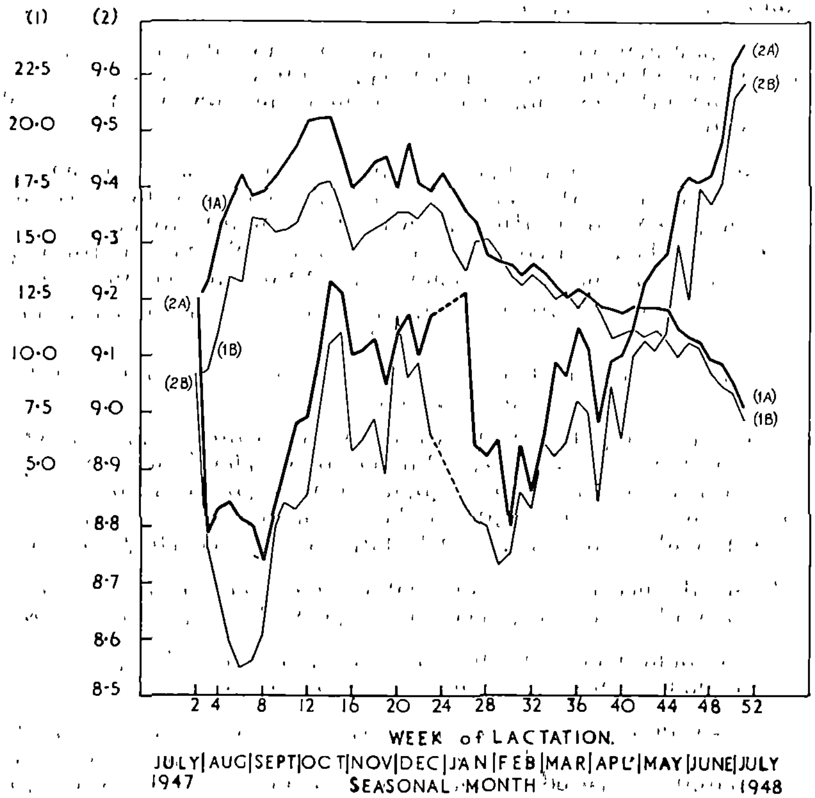

FIG. 4.—Comparison of Lactation Curves:—(1) Yield of Milk in lbs., (2) % Solids not Fat— for (A) MORNING MILK; (B) EVENING MILK, throughout the complete lactation period.

Ordinates of graphs as per Figures 1 and 2.

B. Total Solids and Fat (see Fig. 5).

The character of the fat curves determine to a great degree the nature of the T.S. trends, owing to the greater magnitude of F. variation compared with S.N.F.

Within milk type, trends are identical, but between milk types, analogous, but not identical.

The uniform depression of F. values in the immediate post-parturition stage is shown to be irregularly maintained until both attain trough values in the 13th week of lactation—early October—coinciding with peak milk yields (see Figs. 1, 2, and 3).

A spring depression of fat percentages is thus observed in both morning and evening milk.

The T.S. curves at this stage also reach low values influenced by the greater percentage fall in F. values, as compared with the rise taking place in S.N.F. Such low values in morning milk assume the nature of a trough, such as occurred with evening milk at an earlier stage, and which coincides with depressed F. and minimum S.N.F. percentages.

Strongly oppositional behaviour between evening and morning T.S. and F. values, within the general trends, is observed, similar to that noted for S.N.F., but extending over a longer period.

Morning T.S. and F. values elevate uniformly from spring until late summer, when a temporary but significant depression occurs, coinciding with trough S.N.F. values. Recovery is rapid and values again elevate until the completion of the lactation period.

Evening T.S. and F. curves, on the other hand, present a picture of three depressions, which occur in late winter (7th week of lactation—late August), again in mid-spring (13th week—October), followed by a late summer depression (28th-30th week—January-February). The late summer depression is of much greater magnitude than that shown by morning milk, and this accentuates the elevated values observed during the spring—late summer period.

Evening trends thus resemble S.N.F. trends, but yet retain a similarity to the morning variation. Further, evening milk is characterised by a higher composition level in respect to T.S., due to the direct influence of higher fat percentages.

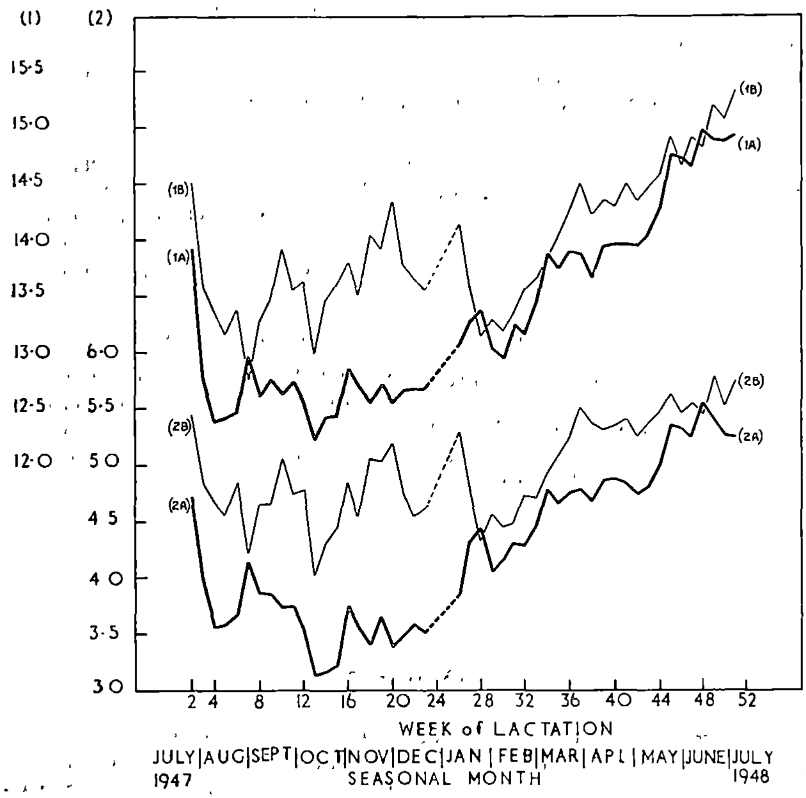

FIG. 5.—Comparison of Lactation Curves:—(1) % Total Solids; (2) % Fat—for (A) MORNING MILK; (B) EVENING MILK; throughout the complete lactation period.
Ordinates of graphs as per Figures 1 and 2.

C. S.N.F. and (T.S. and F.) Curve Interactions (see Figs. 1, 2, & 3).

With morning milk, from the 3rd to the 30th week of lactation (corresponding to the early spring-late summer period), the S.N.F. lactation curve is strongly oppositional in character to the T.S. and F. Curves.

Such curve interaction is also common to evening milk, and, although asserted later in the lactation, is maintained to the same time period.

In the period immediately following calving and in the relatively late stages, all curves, irrespective of milk type, are sympathetic in trend.

D. Yield and S.N.F. Curve Interactions (see Fig. 4).

These curve interactions are rather unique and contrary to the accepted trends associated with the lactation period.

In the immediate post-parturition stage, rising yields are associated with S.N.F. depression, characteristic of the change from colostrum to what is commonly designated "normal milk".

During the spring months of September and October yields progressively increase accompanied by a rise in S.N.F., common peak values being attained, corresponding with the flush period of production.

During the lactation period, when yields are maintained at a relatively high level, high and maintained S.N.F. values are evident.

The depression of S.N.F. values in summer is associated with a material depression in milk yield and hence the trend of the curves remains analogous. With late lactation milk, however, while yield depression is sustained, the S.N.F. curve becomes strongly oppositional, which relationship obtains until completion of lactation.

E. Yield and (T.S. and F.) Curve Interactions (see Figs. 1, 2, & 3).

The complementary nature of the lactation curves is most evident and variations within the general trends maintain the oppositional character. Consideration of such curves stresses the powerful influence of yield on fat percentage of milk and, consequently, on the total solids.

* * * * *

Discussion

Production figures and percentage composition values presented in Table 1 reflect good feeding conditions and cow management during the period of lactation, more especially when it is recorded that the animal was in excellent condition when she calved before and after the completion of the test period. In the 51st week of lactation the average daily yield was of the order of 15 lbs. After this date—1st July, 1948—the evening milking was omitted and the animal dried off preparatory to calving on the 7th October, 1948. Further, such production performance for a rising five-year old grade dairy animal must be regarded as extremely satisfactory from a herd recording viewpoint, which remarks apply equally to the composition standard revealed by the weighted average daily percentage S.N.F. and F. for the morning, evening, and composite evening and morning milk for the whole period.

TABLE 1.—LACTATION SUMMARY: COW "X".

(Non-inclusive of production and per cent composition values from parturition 14th July to morning milk 22nd July, 1947.)

	Total Production.	Morning * Production	Evening Production
Weight Milk lbs.	9,902·58	5,258·52	4,644·06
Weight T.S. lbs.	1,335·14	692·56	642·59
Weight S.N.F. lbs.	892·30	476·77	415·54
Weight F. lbs.	442·84	215·79	227·05
Per cent T.S.	13·48	13·17	13·84
Per cent S.N.F.	9·01	9·07	8·95
Per cent F.	4·47	4·10	4·89

* Inclusive daily milkings, 5th-14th July, 1948

All percentages expressed as weighted average daily values.

A. Solids not Fat.

The S.N.F. behaviour as lactation progresses is found to be radically different to that recorded in the available literature. While the character of trends in the very early and late stages is analogous, the fundamental difference is associated with the early-mid lactation period, which in this test adequately covers the flush conditions of spring and early summer, and wherein the peculiar behaviour of the S.N.F. and its unique relationship to milk yield is demonstrated.

The results confirm previous work associated with the trends of late winter and early spring calvers, *Rees* (unpublished data), which indicated that this type of trend is common both to pure and cross-bred animals; that it is more pronounced under conditions where the animal is dependent for the greater portion of food intake upon available seasonal grazing; and that milk of relatively high composition quality due to breed influence, generally showed greater response to the factors affecting elevation and depression.

It is also noted that the lactation curve closely follows the seasonal variation curve (characteristic of Tasmanian conditions) for bulk market milk in the spring and summer, *Rees* (1949, Figs. 1, 2, and 3).

In view of the above findings, this relationship could be expected, as in spring and early summer, larger cow populations are in the earlier stages of lactation, thus influencing S.N.F. elevation. This uplift would also be aided by the high S.N.F. values of the late lactation milk of cows which calved the previous autumn.

The elevation to peak levels is an orderly and progressive change and, as summer advances, reflects to a greater and greater degree the combined influences of the stages of lactation reached by spring calvers as the autumn calving animals withdraw from the milking herds.

It may be inferred, therefore, that late summer depression in bulk milk is influenced almost wholly by spring calving animals and in like manner, late winter depression by autumn calvers, though in the latter case, no direct evidence is available to indicate that a late winter depression is as characteristic of their lactation curves as late summer depression is of those of the spring calvers.

The question of extreme importance and interest is, whether the stage of lactation exerts a greater influence than the direct and indirect effects of season. A solution could be obtained only if such mid-lactation behaviour could be demonstrated as characteristic of lactation trends initiated in all months of the year. This would imply demonstration of spring and autumn depression and summer and winter elevation associated with the appropriate months of calving.

Present evidence deduced from bulk milk behaviour does not support such an implication, though the favoured spring and autumn calving seasons may be jointly responsible for the absence of such evidence. It is felt that lactation studies of S.N.F. behaviour associated with regulated calving periods throughout the year are well worthy of investigation and such work has already been initiated.

Within lactation, the variation shown by morning and evening values is quite significant, though not of the same magnitude as for fat. Table 2 summarises the maximum degree of variation from the weighted average daily values in Table 1, minimum values being associated with the post-calving—late winter depression, and maximum with late lactation milk, as is recorded for fat.

TABLE 2.

Milk Type.	Weighted Average Daily %.	Minimum Daily %.	Deviation from Weighted Mean.	Maximum Daily %.	Deviation from Weighted Mean
Morning	9·07	8·36	—0·71	9·79	+0·72
Evening	8·95	8·23	—0·72	9·79	+0·84

During the 3rd-8th weeks of lactation, the period of most depressed values (see Fig. 4), it is recorded that only on two occasions did the S.N.F. of morning milk fall below the legal standard of 8·50%, compared with seven occasions for evening milk. These figures represent respectively 6·6% and 23·3% of samples taken for analyses during this six-week time interval.

Such trends illustrate the greater tendency of evening milk to depression and show that, even with animals giving milk of generally high composition quality, the degree of depression can be such that the S.N.F. falls below standard.

Our general experience has been that, in respect to breed influence on milk composition, higher quality milk exhibits greater variation within a lactation than lower quality. This marked variation is evident in the results presented and is in agreement with the findings of *Overman et al* (1929, 1939) : *Overman* (1945), but at variance with that of *Davies* (1932).

While reference to the available literature failed to reveal direct confirmatory evidence relative to the mid-lactation S.N.F. trend presented, the analogous behaviour of bulk milk in spring and summer is amply confirmed, and this should reflect to a great degree the trend of S.N.F. curves of the individual cows composing the herd.

Thus *Andrew* (1928), *Grigg* (1929), *Lesser* (1932), *Rowland* (1944), and *van Rensburg* (1946, 1947) quote the progressive decline in S.N.F. found to occur during late winter, followed by a substantial and immediate rise when the cows are turned on to grass in the spring. *Bartlett et al* (1948) refers to the galactopoietic effect of spring grass on yield and composition. The latter effect is reflected by marked S.N.F. elevation. Their results and observations confirm the unique relationship of the lactation curves for yield and S.N.F. recorded in this report.

Work conducted at the National Institute for Research in Dairying, Reading (Annual Report, 1947), records late winter depression and spring elevation, and also attempts to increase winter S.N.F. content by feeding on a higher plane of nutrition. No statistically significant differences in the composition of the milk were observed, which agrees with the experience of *Lesser*. Yet, after spring grazing commenced, a significant increase in S.N.F. content was at once evident.

Such evidence at once suggests that, during late winter, the stage of lactation effect exerts greater influence than feed intake which is mainly concentrates owing to prevailing seasonal shortages. This effect is apparent in this work.

The findings of *Folley* (1936) and *Folley et al* (1941) who have demonstrated that administration of oestrogens will increase the S.N.F. of cows' milk (enrichment method), and the isolation by *Bartlett et al* (1948) of oestrogens from herbage, clover, and grasses associated with pastures where, as the result of grazing, lactating cows showed increases in milk yield and S.N.F., strongly suggest that spring growth does possess some inherent nutritional factor or regulating hormone or even a hormone precursor, ingestion of which may dominate inexplicably the effect of the cow's own internal hormonal secretions associated with the elaboration and secretion of milk.

Non-isolation of oestrogen from hay by *Bartlett* and his *co-workers* may indicate that this galactopoietic factor is also absent from the parched pastures of late summer, and, therefore, the non-availability to the lactating animal of such sustained external stimulus may also explain the marked fall in S.N.F. which results.

Summer depression is universally acknowledged—drought conditions accentuating the effect so much that often sub-standard milk is produced.

In Tasmania, where the advent of the autumn rains rejuvenates pastures, grazing animals are observed to concentrate on available green growth and an effect analogous to that of spring is noted, with a resultant recovery from the late summer depression.

This occurrence is a feature of the lactation trend presented, but as Cow "X" was at this time in the late stage of lactation, the action of such an external stimulus may be now supplementary to the internal hormonal influences of the period of gestation, the character of the S.N.F. curves reflecting a radical change in composition.

Palmer and Eckles (1917) stated that the period of gestation exerted no influence on the composition of milk apart from inducing an earlier close of lactation. *Bartlett* (1934) records that that the incidence of gestation has an effect on S.N.F., the values shown by pregnant cows elevating and by barren depressing in the late stages of lactation.

Where the lactation period covers the spring and summer season, the observations of *Bartlett* have been observed to apply to Tasmanian conditions, but in both instances spring elevation and summer depression occurred prior to the S.N.F. curves becoming radically different.

B. Fat.

The variation shown by fat as lactation progresses, is shown to be quite considerable. Table 3 summarises the maximum degree of deviation from the weighted average daily values in Table 1 recorded for morning and evening milk, the minimum value being associated with the spring depression noted and the maximum coinciding with the late lactation milk.

TABLE 3.

Milk Type.	Weighted Average Daily %.	Minimum Daily %.	Deviation from Weighted Mean.	Maximum Daily %.	Deviation from Weighted Mean.
Morning	4·10	2·70	—1·40	6·1	+2·00
Evening	4·89	3·50	—1·39	6·3	+1·41

This most significant variation of fat values and the general character of the lactation trend conforms to that found most widely reported throughout the literature, and to which previous reference has been made.

Such trend differences as do occur, appear to be associated with the very early months of lactation and the findings of *Eckles* 1912), *White* and *Judkins* (1918), and *Singleton* (1930) suggest strongly that the condition of the cow at calving influences the level of the fat test; good cow condition at such periods being linked with higher fat contents than if the animal has calved in poor circumstances.

A high composition level of fat, after parturition would, therefore, greatly accentuate the universal depression that occurs in the subsequent period when yields are rapidly rising.

In this work Cow " X " did calve in excellent condition and the spring depression of fat is noted to be most marked.

The complementary nature of yield and fat values of morning and evening milk with progress of lactation, is well substantiated in the literature and by general practical experience. *Turner* (1924) and *Houston & Hale* (1932) refer particularly to such a relationship. *Singleton* (1930), however, has concluded that daily milk yield is not universally an index of the fat test.

During spring, most depressed fat values coincide with peak attainment of yield, common to morning and evening milk, the lower fat level of morning milk being associated with a higher yield. The reduction in fat percentage suffered by the morning milk is of such an order as to depress the fat values below the legal standard of 3·3% which operates for Tasmania. This effect was maintained over a period of three weeks, the weighted average daily values for the 13th, 14th, and 15th lactation week being 3·11%, 3·18%, and 3·22%. During this period, fifteen samples were examined, of which ten or 66·6% were below standard and the minimum value of 2·7% was recorded. Values for evening milk on the other hand were consistently above legal standard for the same period of lactation.

This occurrence is well supported by field experience associated with milk production of high yielding cows in the early stages of lactation and, during the flush conditions of spring, substandard depression of fat, when it occurs, is confined almost entirely to morning bulk milk.

The character of the fat trend is noted to be similar to the variation recorded for bulk market milk, *Rees* (1949), during the comparable period late winter to autumn, spring depression of fat and oppositional behaviour to S.N.F. being common features. During this time interval, the variation shown by bulk milk would be dominated by the proportionally greater numbers of early spring calvers in the herds.

The literature generally would appear to indicate that this basic fat behaviour is an inherent feature of the progress of lactation, complementary to yield and independent of season and calving period. Modification of the trend would be greatly influenced by such factors as the cow's initial condition, her general management and feeding, the primary and secondary effects of climate, &c., which so greatly determine yield behaviour.

Section II.—Results.

LACTATION CURVES FOR FREEZING POINT AND MILK ACIDITY.

(See Figures 6, 7, and 8.)

As recorded in the experimental procedure, actual testing did not commence until seven days post-parturition, and reference to the origin and direction of trends relating to freezing point (F.P.) * and titratable acidity of morning and evening milk, may create the impression that F.P. and acidity values would be high

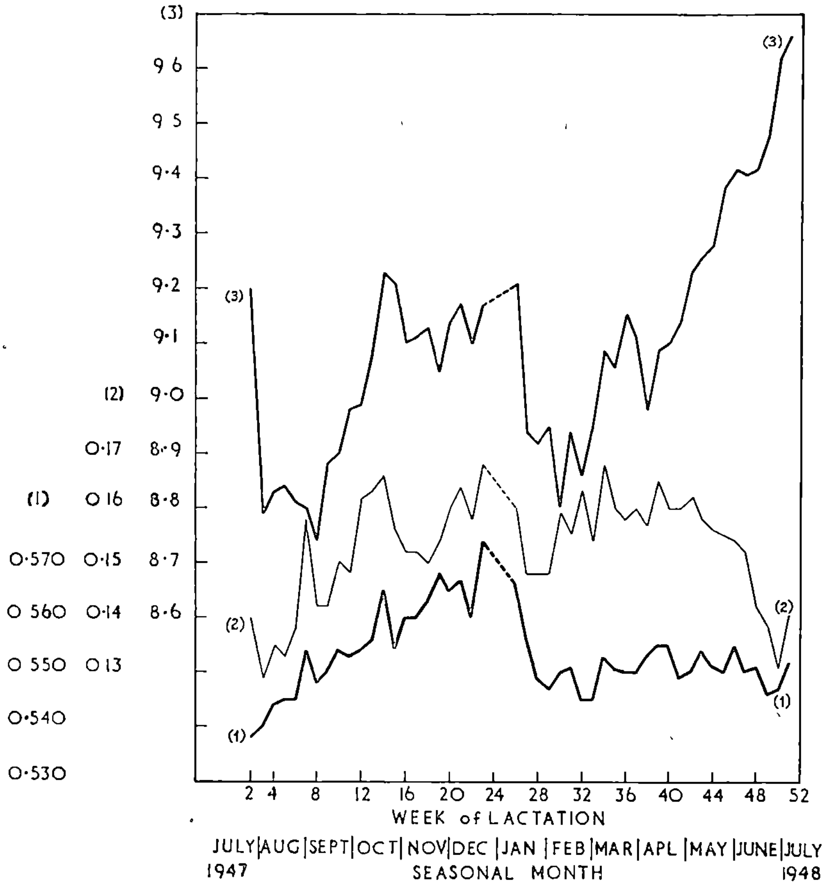

FIG. 6.—Lactation Curves:—(1) Freezing Point Values —°C; (2) % Inherent Titratable Acidity (expressed as lactic acid); (3) % Solids not Fat—from 220 samples of MORNING MILK in respect to Graphs (1) and (2) and 237 samples in respect to Graph (3)—taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily values of the figures obtained for five consecutive MORNING MILKINGS, taken in each week of lactation.

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* With freezing points lower than zero °C, the smaller number is the higher F.P.

F.P D = depression of the F.P. below that of water and is represented by Δ.

A higher or elevation of F P. denotes a decrease in Δ value towards 0°C.

A lower or depression of F P. denotes an increase in Δ value away from 0°C.

and low respectively, immediately after calving. This picture is accentuated by the absence of graph ordinates with respect to F.P., present in degree in regard to acidity, at the commencement of testing, which would indicate the direction of the trend of chemical change taking place from the colostrum stage, as most obviously obtains with T.S., S.N.F., and F. (See Figs. 1 and 2.)

Past experience has demonstrated that the initial colostrum flow has a most depressed F.P. accompanied by a very high titratable acidity, compared with milk subsequently secreted and so relatively the opposite of that depicted at initial testing. This experience is supported in the literature by *Elsdon* (1934), *Engel and Schlag* (1924), while *Schuette and Huebner* (1921) have confirmed that the △ value of colostrum is greater than that of corresponding milk.

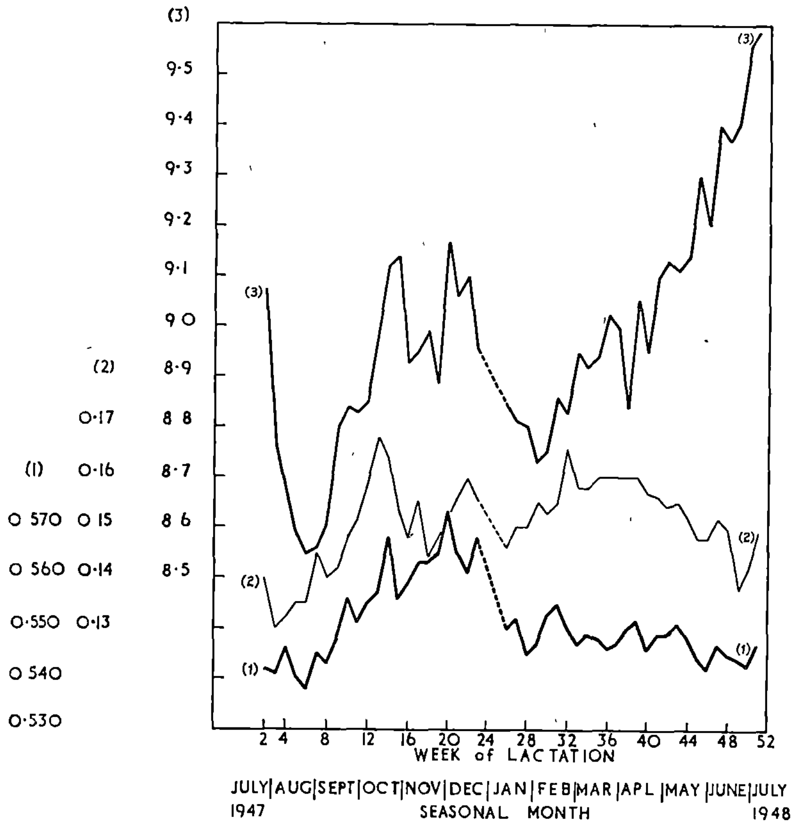

FIG. 7.—Lactation Curves:—(1) Freezing Point Values —°C; (2) % Inherent Titratable Acidity (expressed as lactic acid), (3) % Solids not Fat—from 220 samples of EVENING MILK in respect to Graphs (1) and (2) and 237 samples in respect to Graph (3)—taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily values of the figures obtained for five consecutive EVENING MILKINGS, taken in each week of lactation.

There is, therefore, reasonable justification for postulating that, prior to commencement of testing and covering the seven day time interval from calving, the character of the trends would be one of decreasing △ and titratable acidity values to link up with the first ordinates of the graphs presented.

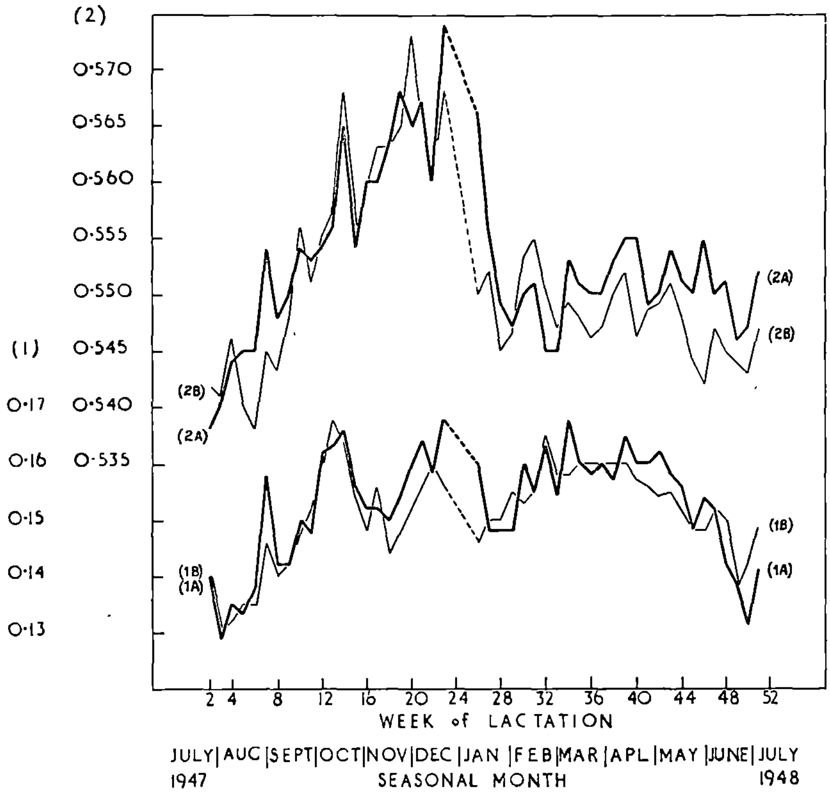

FIG. 8.—Comparison of Lactation Curves:—(1) % Inherent Titratable Acidity (expressed as lactic acid), (2) Freezing Point Values —°C, for (A) MORNING MILK; (B) EVENING MILK, throughout the complete lactation period. Ordinates of graphs as per Figures 6 and 7.

A. Freezing Point.

The F.P. of evening and morning milk was found to vary in a definite and characteristic manner during the observed lactation.

Subsequent to the elevation of the depressed values of colostrum postulated in the immediate post-parturition stage, the F.P. again depressed and remained depressed through spring and early summer, when peak △ values are demonstrated.

With the advent of summer, the F.P. elevated quickly becoming apparently stabilised in late January-early February corresponding to the 28th-29th week of lactation.

The evening F.P. is observed to elevate prior to the morning (see Fig. 8). Due, however, to the absence of values for the 24th and 25th week of lactation, most depressed morning △ values may have been reached in this period corresponding to the attainment of peak S.N.F. values as apply with evening milk (see Fig. 7). If so, the differential time interval of three weeks which is noted would be extended.

Such behaviour is thus observed to be identical with that recorded for S.N.F. and the character of their lactation curves shown to be similar and sustained from calving until a relatively late stage in lactation.

When the S.N.F. decreases, the F.P. elevates, the troughs of most depressed S.N.F. values coinciding in lactation and seasonal period with the most elevated F.P. values. The converse is shown to apply equally in association with elevating S.N.F., peak S.N.F., and greatest $\triangle$ values, which are attained during spring and early summer.

During lactation, the general degree of F.P. depression was greater for morning milk, though it did not obtain strictly as in the case of S.N.F.

B. Titratable Acidity.

Titratable acidity values, irrespective of milk type, are also observed to change materially in an apparently orderly and controlled manner, maintaining a trend behaviour during the early-mid lactation analogous to that demonstrated for F.P. and S.N.F.

Associated with late lactation milk, a significant but temporary rise is apparent in sympathy with S.N.F. This relationship, however, gradually becomes oppositional. Values as low as 0·08% were obtained in the last week of lactation, which ordinate is not included in the graphical presentation, as the experimental animal at that period was being milked but once per diem and yielding approximately 5 lb. of milk.

In regard to the differential level of morning and evening values, morning milk is shown generally to exhibit slightly greater acidity figures but, as with F.P., such a condition was not maintained uniformly throughout the period of lactation.

* * * * *

Discussion

A. Freezing Point.

The relative constancy of the osmotic pressure of milk, has been widely referred to and stressed by investigators throughout the literature, implying that the concentration of water soluble materials which influence F.P. also remain relatively constant; a deficiency or surplus in one influencing S.N.F. component, being balanced as regards osmotic pressure by a corresponding increase or decrease in another, the composition of milk thus accommodating itself to suit this isotonic constancy.

The observed orderly and progressive variation of F.P. within lactation does not support this hypothesis of "maintenance of isotonic equilibrium", but is in keeping with the opinion previously advanced, *Rees* (1949), that the osmotic pressure of blood and milk would appear to be greatly influenced by the character of available seasonal grazing.

The extreme degree of variation shown by weighted average weekly and daily △ values for morning and evening milk during the period of △ increase in spring and early summer, with analogous figures depicting S.N.F. increase, are presented in Table 4.

TABLE 4.

	Milk Type.	△ °C			S.N.F. %			Variation %	
		Min.	Max.	Diff.	Min.	Max.	Diff.	△	S.N.F.
Daily values	Morning	0·523	0·582	0·059	8·36	9·44	1·08	11·3	12·9
	Evening	0·530	0·586	0·056	8·23	9·45	1·22	10·6	14·8
Weighted average weekly values	Morning	0·538	0·574	0·036	8·74	9·23	0·49	6·7	5·6
	Evening	0·538	0·573	0·035	8·55	9·17	0·62	6·5	7·2

The percentage variation figures for △ and S.N.F. reveal that the relative range of variation of F.P. is analogous to that shown for S.N.F. and the relevant graph interpretation also indicates that similar remarks apply to that stage of lactation covering the late summer, when △ and S.N.F. values decrease.

The extremes of variation are noted to conform with the results obtained by those many investigators whose recordings have been summarised by *Elsdon* and *Walker* (1942, Table 86, p. 104), and *Davies* (1939, Table C, IV, p. 287), and are in close agreement with those of *Tocher* (1925), *Hortvet* (1921), *Bailey* (1922), *Stubbs* and *Elsdon* (1934), *Denis-Lester* (1937), *Aschaffenburg* and *Veinoglou* (1944), *Aschaffenburg* and *Temple* (1941), which deal with the milk of individual cows.

Such evidence must stress the necessity for reorientation of views relating to the so-called "constancy of the F.P. of milk", particularly in regard to the setting of legal standards. Greater appreciation of the range of variation, which genuine bulk milk and individual cow samples can show from assumed means, is necessary, and realisation that, associated with the progressive composition change in milk, the F.P. can exhibit significant fluctuations, in a degree at least comparable with that shown by corresponding S.N.F. values.

The author is in entire agreement with the expressed viewpoint of *Aschaffenburg* and *Veinoglou* (1944, p. 280) that in reporting on an adulterated sample it would be far preferable "to state the minimum percentage of added water, calculated on the basis of limiting △ value, than endeavour to estimate the probable amount of extraneous water from an assumed mean △ value ".

The F.P. curves of Figures 6, 7, and 8 would appear to suggest strongly a marked effect of " stage of lactation " and be, therefore, opposed to the findings of *Denis-Lester* (1937) and *Aschaffenburg* and *co-workers* (1941, 1944). Whether such overall influence should be regarded as primary or secondary to seasonal effect, cannot be determined from this work. But, it is noted, that a marked osmotic disturbance commenced in spring and changed in an orderly and progressive manner until late summer, when △ values became apparently stabilised.

This is highly suggestive that the qualitative and quantitative intake of food by the dairy animal, is the dominant influence associated with this seasonal period.

It is not, however, considered to be the sole factor, otherwise the lactation curve would have risen, implying △ increase, in the autumn, with the advent of the rains and changes in pasture condition, in an analogous manner to that obtaining in spring.

As this did not occur, the stage of lactation must be considered as influencing the F.P. trend, probably aided by the " period of gestation " effect. Similar remarks would apply to the period of change from colostrum to marketable milk condition.

The mid-lactation behaviour is noted to conform to bulk milk trends previously reported to occur in the corresponding seasonal period, *Rees* (1949), and points to the operation and influence of this common feed factor, tending to influence all lactating cows in a similar way at the same time, the degree of influence, however, being governed by the stage of lactation of the cow population.

Bulk milk trends showed a distinct increase of △ values in the autumn, though in degree not so pronounced as the spring effect. As the composition quality and bulk of such milk would be dominated by incoming and flushing autumn calvers, it may be inferred that " an autumn feed effect " becomes operative and dominant, over-riding the stabilised △ values of the late lactation milk of cows which calved the previous spring.

In the light of such evidence, therefore, seasonal effect, or more strictly a factor associated with season, would appear to dominate F.P. behaviour but it is not the only factor. The stage of lactation must be considered in bulk milk trend interpretation, not only in regard to F.P. but applying also to all the physical and chemical " constants " of milk.

The F.P. of milk is generally regarded as free from seasonal variation, *Stubbs* and *Elsdon* (1934), *Denis-Lester* (1937) ; but the extensive work of *Aschaffenburg* and *co-workers, Temple* and *Veinoglou* (1941, 1944), dealing with bulk milk and individual cow samples with progression of lactation, confirm the original observations of *Buchanan* and *Lowman* (1929) as to the definite existence of seasonal variation.

However, the analogous character of their recorded F.P. curves are diametrically opposed to the lactation trends described here, and bulk milk behaviour previously reported, *Rees* (1949).

While mutually supporting the hypothesis that an alteration in the osmotic balance of milk occurs associated with grazing of fresh pasture growth, they demonstrate $\triangle$ values to decrease in the spring, that is for the F.P. to elevate, and for $\triangle$ values to increase through summer to peak depression values, in autumn. Thus, during this latter period, the F.P. progressively depresses. Subsequently $\triangle$ values decrease through winter until re-attainment of the elevated F.P. values of spring.

In regard to bulk milk behaviour, the common features of our experience are the depressed F.P. values of autumn and the elevation of F.P. values through the winter.

We have found that the galactopoietic effect of spring grazing not only increases the percentage concentration of S.N.F. from the trough values of late winter, but also, in harmony, increases $\triangle$ values. Further, this effect is alike common to bulk milk and that of the individual herd unit.

The dystrophic effect of late summer grazing, in relation to S.N.F., is likewise accompanied by a sympathetic decrease in $\triangle$ values.

B. Titratable Acidity.

The wide variation shown by the inherent titratable acidity of fresh milk, is well established in the literature, but no references could be consulted dealing with the character of this trend with progress of lactation.

Titration values, for pedagogic purposes, are expressed as a percentage of lactic acid, when in reality they are a measure of the quantity of alkali required to change the pH of the various milk buffer systems from normal and original pH values of about 6·6 to that of 8·3.

Acidity values are therefore dependent on the concentration of buffer constituents present in the milk which in turn are related to the S.N.F. content and further, buffer activity is greatest on the acid side of normal pH values.

Milk exhibits considerable buffering action at the pH of normal samples, and the proteins, citrates, phosphates and bicarbonates, that is, the weak anions, are considered to be the principal buffers in milk, of which the protein and phosphate fractions exert the greatest effect. *Elsdon* and *Walker* (1942, p. 90), *Davies* (1939, p. 305).

In this work an intimate correlation is shown to prevail between the lactation curves for apparent acidity and those of S.N.F. and protein, which ceases, however, in the late stages of lactation.

At first this would appear surprising, as the S.N.F. and protein fractions are then shown to increase materially in concentration. However, it must be appreciated that the acidity of fresh milk is largely due to the soluble acid phosphate system, since titration values of sera are roughly the same as for the milk from which they are separated, *Davies* (1939, p. 54).

Therefore the titratable acidity curves must, in the main, reflect the variation within the lactation of the soluble acid phosphate fraction of milk, which can be regarded as similar to, but not identical with, the S.N.F. and protein behaviour and as totally dissimilar to the ash variation.

Evidence is presented in this work, under the section dealing with the mechanism of F.P. variation, to prove this contention, and, therefore, to explain the mechanism of acidity variation and the lack of correlation shown between S.N.F. and acidity in the late stages of lactation.

The factors which are considered to influence S.N.F. generally and F.P. specifically, must also directly affect titratable acidity values. Rising values are associated with the fresh growth of spring and autumn, and decreasing values with the parched and stubble condition of pasture in the late summer. Rapid depression is also noted with late lactation milk, and in the immediate post-parturition stage, even though pasture condition at these seasons provides a distinct contrast to that prevailing in late summer.

Okulitch and *Golding* (1932) do report a monthly variation in pH and buffer values and state that a change from indoor to outdoor conditions of feeding causes a definite lowering of the pH of the milk produced and, therefore, an increase in the buffer value. Their work is supported by *Pelekhov* (1926) and *Davies* and *Provan* (1928) in that the pasturing of cows results in an increase of milk constituents of importance in buffering.

Such findings are in agreement with the results presented.

On the other hand, *Maynard* (1929) and *Watson* (1931) concluded that a change of rations or of the pasturing of the herd, had a negligible influence upon the buffer value of milk.

Section III.

MECHANISM OF S.N.F. VARIATION.

(See Figures 9, 10, and 11.)

The trend behaviour of each curve for total protein, lactose and ash, is shown to be characteristic and distinct and between milk types, those of corresponding S.N.F. components, to be analogous.

The mechanism of S.N.F. behaviour in relation to the four seasons which the lactation period covers, is considered.

The late winter depression of S.N.F., which occurs approximately two months after calving, is characterised by protein values falling until they reach a minimum, by depressing ash and rising lactose; the greater percentage reduction in protein and ash values in relation to lactose increase, determining the character of S.N.F. behaviour.

During the spring, a significant elevation of protein values associated with a continuation of lactose increase to peak levels and a minor ash decrease, explain the rapid rise evident in the S.N.F. trend.

Lactose values are maintained at a relatively high level during early mid-summer, with a tendency, however, to a slight depression later, while the protein fraction continues to increase in value till it reaches its maximum, and the ash to decrease still further.

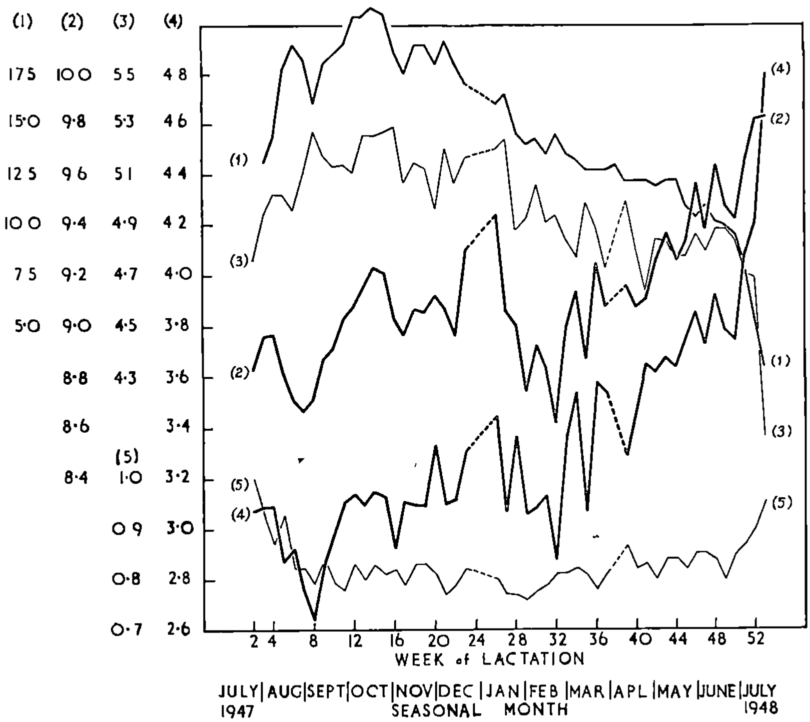

FIG. 9—Graphs illustrating mechanism of Solids not Fat variation—MORNING MILK Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Solids not Fat, (3) % Lactose (monohydrate); (4) % Total Proteins (by difference); (5) % Ash. Ordinates of graphs represent the figure values obtained for a "MORNING'S MILKING" taken from Cow "X" on a constant day within each lactation week and conducted throughout the complete lactation period.

Whereas the increase of S.N.F. in spring is due to common elevation of its two major constituents, the maintained high S.N.F. and even continued elevation in mid-summer is due entirely to the progressive influence of increasing protein content.

With the advent of late summer, the drastic change in milk composition is characterised by a common depression of all the S.N.F. constituents. This common trend occurs only at this stage in the cow's lactation.

The late lactation trends in autumn and early winter exhibit a marked and sustained increase of protein values; lactose values continue to decline while the ash reveals a progressive increase. The S.N.F. curves of morning and evening milk are thus noted to recover significantly from the late summer depression, increasing to maximum values at completion of the lactation.

Associated with the periods of significant change in milk composition, particularly during the summer depression and autumn elevation of S.N.F., evening protein values depress and elevate prior to morning values, the differential time period in the stage of lactation being of the order of three weeks.

In regard to lactose variation, such time points are not so evident, owing to the marked difference in character of the trend, but associated with the attainment of peak values in the late

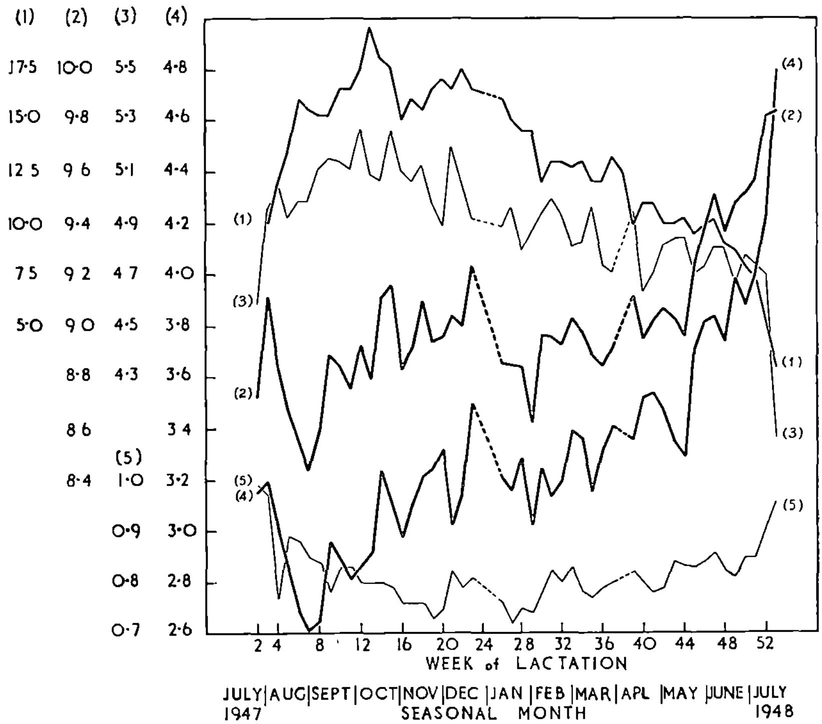

Fig. 10.—Graphs illustrating mechanism of Solids not Fat variation—EVENING MILK. Lactation Curves:—(1) Yield of Milk in lbs.; (2) % Solids not Fat; (3) % Lactose (monohydrate); (4) % Total Proteins (by difference); (5) % Ash. Ordinates of graphs represent the figure values obtained for an "EVENING'S MILKING" taken from Cow "X" on a constant day within each lactation week and conducted through out the complete lactation period.

spring, it will be noted that with morning milk, high lactose values are maintained over a longer period of lactation than with evening milk, which exhibits a stronger and earlier tendency to depress.

Similar remarks apply to the lactation curves for ash. Minimum values are demonstrated for both milk types in the mid-late summer, the evening minimum occurring two weeks earlier than the morning minimum.

The behaviour of each S.N.F. constituent is thus observed to be analogous with that previously recorded for S.N.F. and F.P.

With progress of lactation, curve interactions as between yield and S.N.F. constituents are shown to be quite dissimilar, yield and lactose trends being analogous and both opposed to that of ash, while the relationship between yield and protein is demonstrated to conform to that unique interaction previously described for yield and S.N.F., due to the very similar curve behaviour of protein and S.N.F.

Total protein content may be thus regarded as the key fraction which so greatly determines S.N.F. variation, even though at all stages, very late lactation milk excepted, its percentage concentration in milk is greatly inferior to that of lactose.

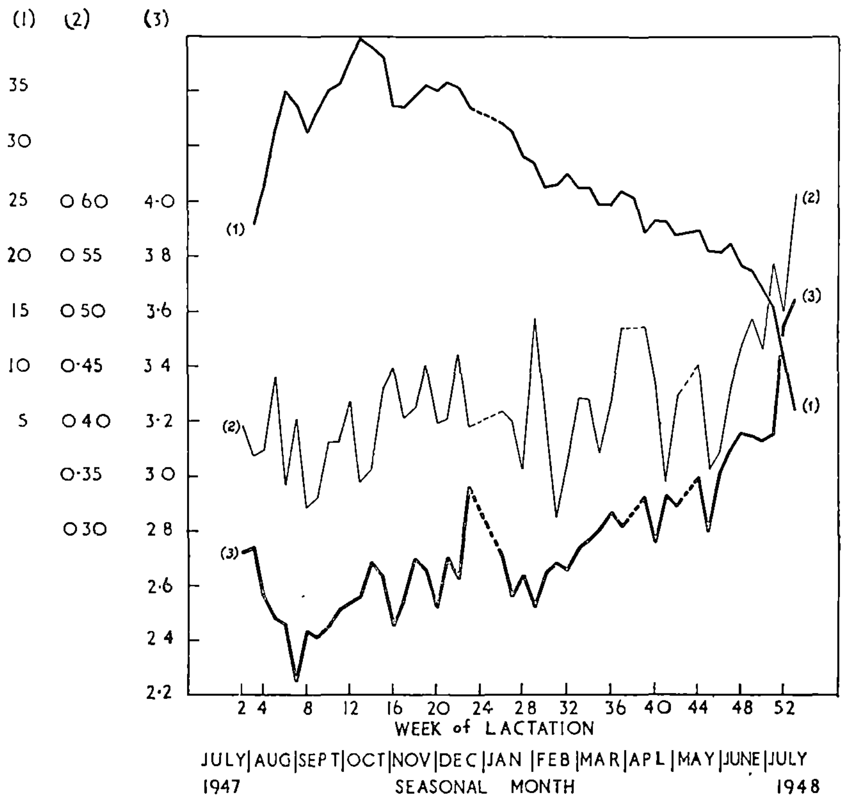

FIG. 11. Graphs illustrating Variation of Protein Fractions.
Lactation Curves:—(1) Total Yield of Milk in lbs.; (2) % Lact-Albumin (including globulin fraction); (3) % Casein
Ordinates of graphs represent the figure values obtained for a weighted "COMPOSITE SAMPLE" of milk taken from a consecutive EVENING and MORNING milking of Cow "X", constant within each lactation week and conducted throughout the complete lactation period

Figure 11 shows the variation of the protein fractions, casein and albumin directly estimated from composite samples of evening and morning milk.

Between protein types, the nature of the curves are similar and also analogous to that of the total protein fractions depicted in Figures 9 and 10.

Casein and albumin trends therefore reveal late winter and late summer depressions and conform to the unique behaviour of S.N.F. during the intervening seasonal period.

From inspection of the curve interactions within the general trends of protein variation, one cannot disregard the evident and markedly " complementary character of casein and lacto-albumin values ". The occurrence is far too orderly and regular to be dismissed as irrelevant in the secretion of milk.

The work of *Van Slyke* (1908), *Eckles and Shaw* (1913), *Tocher* (1926), *Lemvigh* (1935), and *Azarme* (1938) relative to the effect of stage of lactation on the casein and total protein content of milk, do not reflect the depression of mid-lactation milk occurring in late summer, but it is supported by *Veale* (1929).

References directly dealing with the study of the lactose trend appear to be very restricted, such information as is available providing evidence of an indirect nature, and associated with bulk milk studies. Thus the depressed S.N.F. values of late summer have been found by *Cranfield, Griffiths, and Ling* (1927), *Lesser* (1932), *Turner* (1936), *Davies* (1937), *Overman* (1945), *Purchase* and *Reverberi* (1946), and from investigational work carried out at the National Institute for Research in Dairying, Reading (Annual Report, 1947), to be due to a common depression of lactose and protein.

Such observations are in agreement with those reported here and appear therefore, to be a feature of the stage of lactation at that period of the year.

The positive correlation indicated for yield and percentage lactose, confirms the findings of *Tocher* (1925), while the lactation curve for ash is analogous to that recorded by *Jacobsen* and *Wallis* (1939).

Section IV.

MECHANISM OF FREEZING POINT VARIATION.

(See Figures 12, 13, 14, 15, and 16.)

The freezing point of milk, or, more correctly, the depression of the freezing point of water in milk, is directly related to the osmotic pressure, which in turn is dependent on the quantitative solution of molecules and ions.

The influence on this additive property is due mainly to the inherent lactose and soluble salt fractions of the S.N.F., as the fat has no effect and that of the proteins is negligible or too small for cryoscopic measurement.

Studies by *Coste* and *Shellbourne* (1919), *Porcher* and *Chevallier* (1923), and *Staub* (1926) dealing with the partial depressions of the F.P. caused by the various compounds and salt combinations in milk, stress the major influence of lactose and chlorides, accounting for approximately 75 per cent of the F.P. depression, compared with the relatively smaller, though still very significant, effect of citrates and phosphates in true solution and the minor contributions of non-protein N, Colloidal complexes, sulphate, and bicarbonate.

Post (1926), further confirming this viewpoint, has suggested that the lactose and chlorides in milk are responsible for nearly 80 per cent of the osmotic pressure. Of these two S.N.F. fractions, lactose exerts approximately double the effect of chlorides, *Coste* and *Shellbourne* and *Porcher* and *Chevallier* suggesting respective degrees of influence for lactose to be of the order of 45 per cent-53 per cent of the total F.P. depression.

Throughout the literature, the reciprocal variation of chloride and lactose in milk is stressed, an assumption which demands the complementary regulation of isotonicity when either of these milk constituents varies. Further, *Staub* (1926) states that the partial depression of the F.P. caused by the phosphates and citrates, the most important of the non-lactose-chloride fractions of the S.N.F. in regard to its effect on $\triangle$, is a uniform contribution.

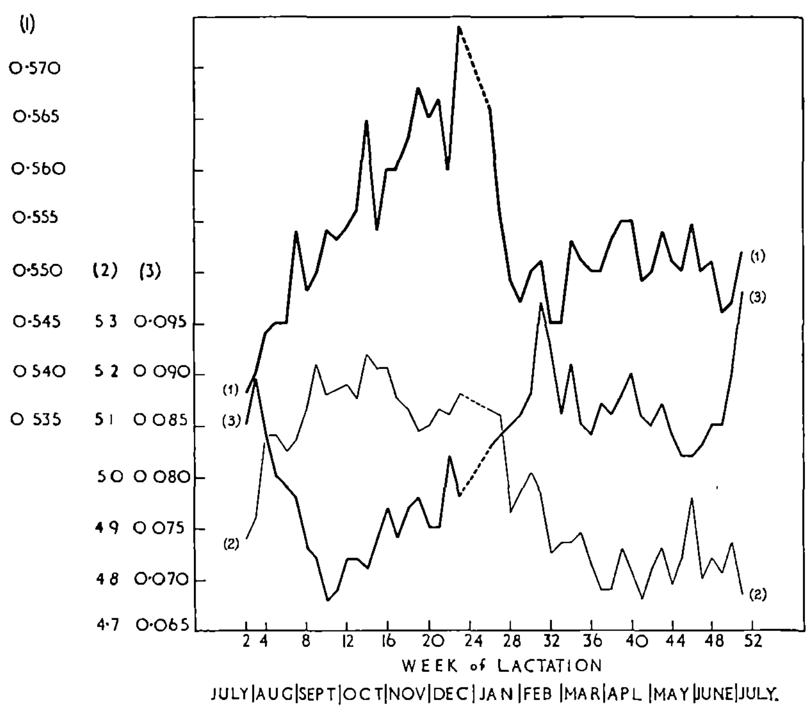

FIG. 12.—Graphs depicting reciprocal variation of Lactose and Total Chloride with changing Freezing Point values—MORNING MILK.

Lactation Curves:—(1) Freezing Point Values —°C, (2) % Lactose (monohydrate), (3) % Total Chloride—from 220 samples of MORNING MILK in respect to Graph (1) and 227 samples in respect to Graphs (2) and (3), taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily values of the figures obtained for five consecutive "MORNING MILKINGS" taken in each week of lactation.

If such facts are to be accepted, △ values for milk should be uniform and not show the progressive and orderly change demonstrated in this work. Also the curve interactions of lactose and chloride should be strongly and strictly complementary throughout the entire lactation period.

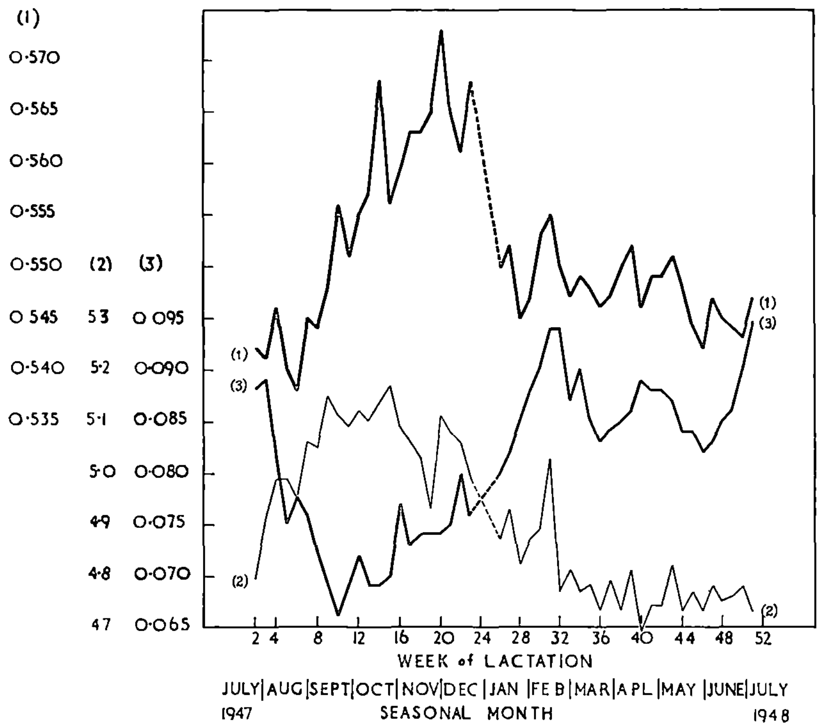

FIG. 13.—Graphs depicting reciprocal variation of Lactose and Total Chloride with changing Freezing Point Values—EVENING MILK.

Lactation Curves:—(1) Freezing Point Values. °C, (2) % Lactose (monohydrate); (3) % Total Chloride—from 220 samples of EVENING MILK in respect to Graph (1) and 227 samples in respect to Graphs (2) and (3), taken from Cow "X" during the complete lactation period.

Ordinates of graphs represent the weighted average daily values of the figures obtained for five consecutive "EVENING MILKINGS" taken in each week of lactation.

Figures 12 and 13 depict the variation, as lactation progresses, of the percentage concentration of lactose and total chlorides (expressed as Cl), for morning and evening milk respectively, with the corresponding lactation curves for F.P. Curve interaction within milk type is shown to be analogous.

Post-parturition, lactose, and chloride trends appear to be strongly complementary, total chlorides depressing and lactose elevating, yet, isotonic constancy is not maintained, △ values significantly increasing.

The decline of chlorides becomes arrested in early spring, when minimum values are evident. At this stage in lactation, the complementary behaviour ceases, chloride and lactose trends becoming strongly sympathetic and the F.P. curve elevates still further, inferring a further increase in $\triangle$ values.

From late spring to early summer, lactose values are maintained at relatively high levels with a tendency, however, to depress, while the character of the rising chloride curves is much steeper, which imply a greater relative change in constituent concentration. The curves, it will be noted, are becoming complementary again, and this is most marked in mid-late summer.

The lactose decrease and chloride increase does not stabilise molecular and ionic equilibrium in the milk, $\triangle$ values decreasing rapidly as is illustrated by the steepness of the F.P. curve.

In the autumn and winter, with lactation materially advanced, the F.P. apparently stabilises around the elevated values attained during late summer, indicating relative maintenance of isotonic equilibrium within the milk and this assumption is supported by the more or less stabilised lactose and chloride curves, which, however, within their general trend, still remain opposed.

The milk of the extremely late lactation period reveals a further and material increase in chlorides, while lactose depression accentuates. The severity and degree of this rise and fall in values is stressed when comparison is made of the ordinates of F.P., lactose and chlorides secured in the 51st week of lactation, as in the graphical presentation of morning milk, with the respective values obtained for the last morning sample withdrawn in the 53rd week, when milking was being practised once daily.

TABLE 5.

Week of Lactation.	$\triangle$ °C.	% Lactose.	% Total Chlorides.
51st	0·552	4·767	0·0975
53rd	0·548	3·970	0·1520

Such values reveal that while the osmotic equilibrium of the milk has remained relatively constant, the lactose content decreased 16·7% and the total chlorides increased 55·9%.

Such evidence, while supporting in principle the reciprocity of lactose and chloride variation in milk, strongly indicates that the relationship is not a linear one; that it does not result in complementary regulation of milk isotonicity, and further, that the non-lactose-chloride fraction of the S.N.F. which influences $\triangle$ values (referred to as the residual fraction and the residual $\triangle$ effect in subsequent discussion) is not constant in effect, and, relatively, just as variable as the lactose or the chloride concentration.

The veracity of such an assumption cannot be determined directly, as quantitative values expressing the percentage concentration of the residual fraction are lacking. Alternatively, the equivalent partial △ contributed to milk △ values has been calculated by the method of difference in the following manner:—

Table 6 presents normal △ values for varying molar concentrations of lactose and equivalent percentage concentrations W/W of lactose ($C_{12}H_{22}O_{11}$) and lactose monohydrate ($C_{12}H_{22}O_{11} + H_2O$), covering the range of variation of lactose determinations, recorded as the monohydrate in this study.

TABLE 6.

% W/W Lactose—Lactose Monohydrate and △ °C Relationship.

Concentration $C_{12}H_{22}O_{11}$ in gram molecules per 1000 gr. H_2O ..	0·0597	0·0750	0·0904	0·1006	0·1060	0·1154	0·1219	0·1306	0·1378	0·1458	0·1539	0·1612
Equivalent % W/W $C_{12}H_{22}O_{11}$	2·000	2·500	3·000	3·325	3·500	3·800	4·000	4·275	4·500	4·750	5·000	5·225
Equivalent % W/W $C_{12}H_{22}O_{11} + H_2O$	2·106	2·632	3·158	3·500	3·684	4·000	4·211	4·500	4·737	5·000	5·263	5·500
△ °C Normal	0·1109	0·1394	0·1681	0·1869	0·1972	0·2147	0·2266	0·2428	0·2562	0·2711	0·2862	0·2997

All values have been calculated from the relation—

$$\triangle = K \frac{N}{W};$$

where $\triangle$ is the lowering of the F.P. produced when "N" gram molecules of solute are dissolved in "W" grams of solvent, "K" is the freezing point or cryoscopic constant which depends only on the solvent, which in the case of water is equal to 1859. The above formula is strictly applicable only to normally behaving organic non-electrolytic solutes like the sugars.

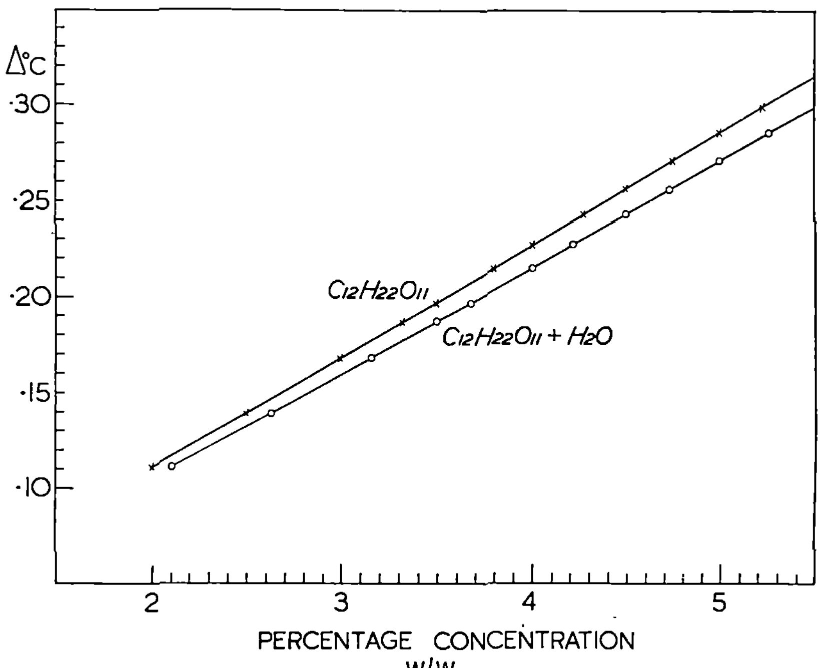

FIG. 14.—Graphs illustrating the relationship between $\triangle$ and percentage concentration W/W of lactose and lactose monohydrate.

The relationship between calculated $\triangle$ values and sugar concentrations is presented graphically in Figure 14, where it is seen to be non-linear and therefore at variance with the proportional relationship which obtains between molar concentration of solute per 1000 grams H_2O and $\triangle$.

From the lactose monohydrate—$\triangle$ curve, $\triangle$ values have been determined, equivalent to weighted average lactose monohydrate values for each week of lactation (see Tables A and B, Appendix), and incorporated in Table E (Appendix).

In a manner similar to that adopted for lactose, normal $\triangle$ values were determined for varying molar concentrations of NaCl and KCl and equivalent percentage concentrations W/W of NaCl: KCl and Cl, covering the range of variation of experimentally determined total chlorides (see Tables A and B—Appendix). Such normal $\triangle$ values are recorded in Table 7.

It is apparent that for equal molar concentrations of NaCl and KCl in the range of molarity 0·01 to 0·10, while the equivalent concentrations of molecular chloride are radically dissimilar, that of Cl in both instances may, for practical purposes, be regarded as identical. Equivalent data for 0·2 molar concentration, entirely beyond the range of experimental chloride determination in this work, is included to demonstrate the commencement of divergence, which intensifies with increase of molar concentration of the salts.

Because of this fortuitous equality of equivalent Cl concentration at the specified dilutions, there is no necessity for due regard to be paid to the molecular union of chlorine either with potassium or sodium in the milk samples, when considering the effect on △ values.

As such normal △ values are not applicable to salts and electrolytes, owing to ionisation, the correct abnormal △ values have been determined from the expression—

$$[\triangle \text{ normal} \times (1 + \gamma)]$$

where γ is the activity coefficient, representing the ratio of mean-ion activity to the molality. (See Appendix for method adopted in calculating the correction to be applied to normal △ values.)

TABLE 7.

% W/W NaCl—Cl and △ °C Relationship.

Concentration NaCl in gram-molecules per 1000 g H_2O	Equivalent % W/W NaCl	Equivalent % W/W Cl	△ °C Normal	Activity * Coefficient γ	Corrected Van't Hoff Coefficient ($i = 1 + \gamma$)	△ °C Observed (△ Normal $\times (1 + \gamma)$)
0·01	0·058	0·035	0·01859	0·922	1·922	0 0357
0·02	0·117	0·071	0·03718	0·892	1·892	0·0704
0·05	0·291	0·177	0·09295	0·842	1·842	0·1712
0·10	0·581	0·353	0·18590	0·798	1·798	0·3343
0·20	1·156	0·701	0·37180	0·752	1·752	0·6513

% W/W KCl—Cl and △ °C Relationship.

Concentration KCl in gram-molecules per 1000 g H_2O	Equivalent % W/W KCl	Equivalent % W/W Cl	△ °C Normal.	Activity * Coefficient γ	Corrected Van't Hoff Coefficient ($i = 1 + \gamma$)	△ °C. Observed (△ Normal $\times (1 + \gamma)$)
0·01	0·074	0·035	0·01859	0·922	1·922	0·0357
0·02	0·149	0·071	0·03718	0·892	1·892	0·0704
0·05	0·371	0·177	0·09295	0·840	1·840	0·1710
0·10	0·740	0·352	0·18590	0·794	1·794	0·3335
0·20	1·469	0·699	0·37180	0·749	1·749	0·6503

* Values of activity coefficients for NaCl and KCl at different molar concentrations in grams of solute per 1000 g. H_2O after *Findlay* (1941).

The relationship between calculated Δ values and percentage concentration of Cl and equivalent NaCl and KCl, are presented graphically in Figure 15 and, as noted for lactose, shown to be non-linear.

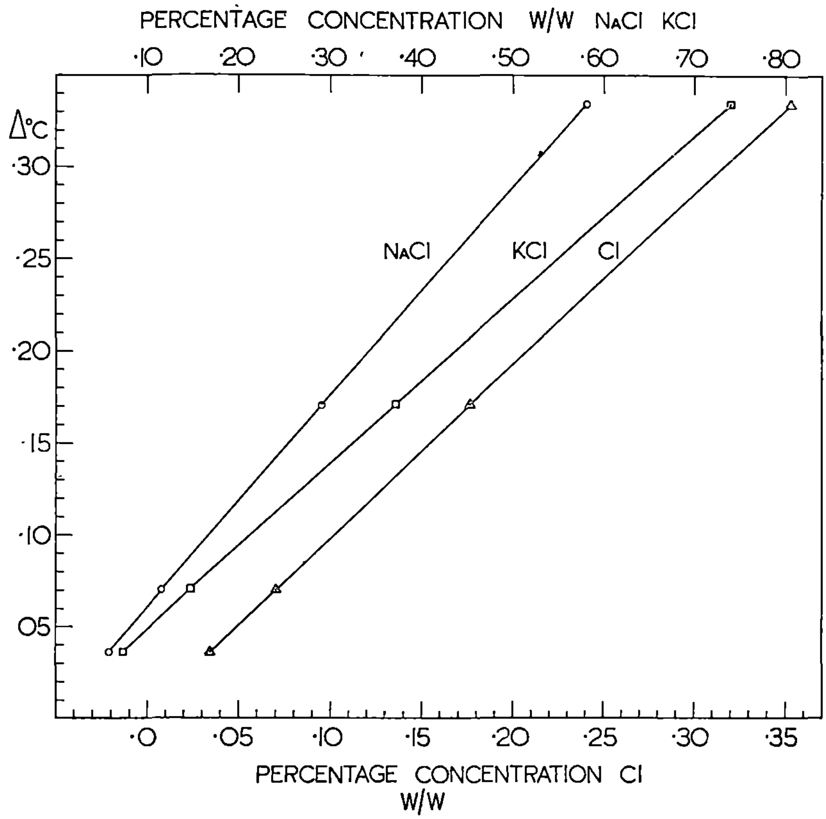

Fig. 15.—Graphs illustrating the relationship between Δ and percentage concentration W/W of sodium chloride, potassium chloride and chloride.

Δ values have been obtained corresponding to the experimentally determined total chloride values, and incorporated in Table E (Appendix).

Residual Δ values have been calculated by difference from the expression:—

$$\text{Residual } \Delta = \text{Milk } \Delta - (\text{Lactose } \Delta + \text{Chloride } \Delta)$$

and for the purpose of illustrating the mechanism of F.P. variation, the quantitative contributions of lactose, chloride, (lactose + chloride), and residual Δ to milk Δ, are graphically presented in Figure 16, while Table 8 shows the degree of Δ variations for S.N.F. fractions affecting the F.P. of milk.

TABLE 8.*

Δ	A.M. Milk.				P.M. Milk.			
	Av.	Max.	Min.	Max. Var.	Av.	Max.	Min.	Max. Var.
Milk	·553	·574	·538	·036	·551	·573	·538	·035
Lactose ...	·271	·285	·258	·027	·266	·281	·255	·026
Chloride ..	·080	**·096**	**·067**	·029	·080	·093	·065	·028
Residual .	·202	·218	·186	·032	·205	·224	·188	·036

* Δ values for the 52nd and 53rd week of lactation are omitted as during this period the animal was being dried off and milking conducted once daily.

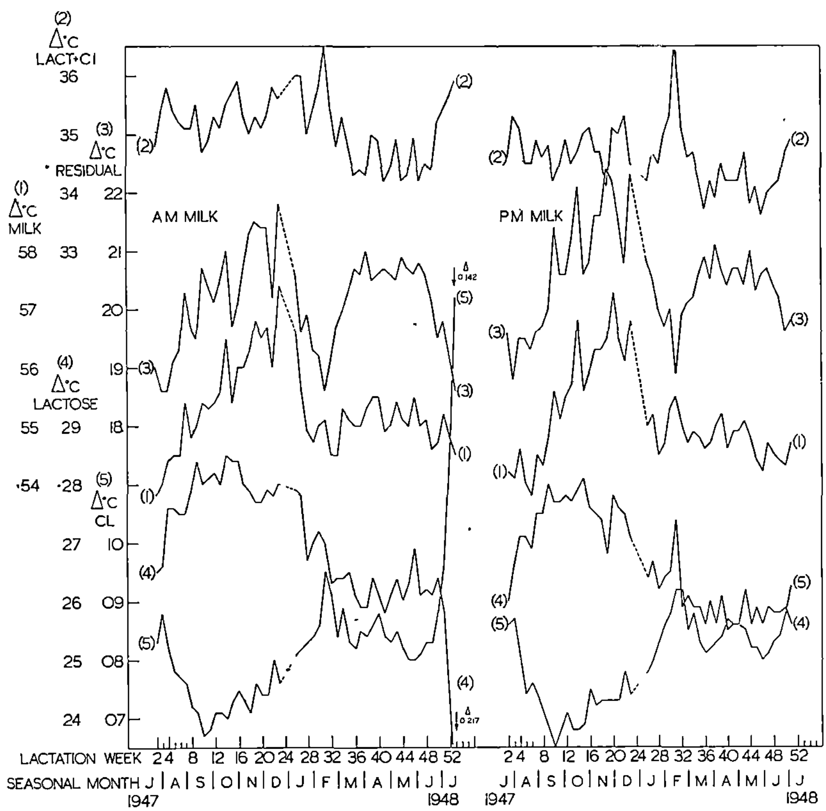

FIG. 16.—Graphs illustrating the mechanism of Freezing Point Variation.

This evidence confirms the findings of *Porcher* and *Chevallier* (1923) that lactose contributes most to milk Δ; that the partial Δ caused by the residual fraction is greater than the chloride effect;

and confirms the previous assumption that the apparent reciprocal variation of lactose and chloride does not result in the regulation of milk isotonicity.

Residual △ variation is not constant in effect, but shown to be equally as variable as lactose or chloride.

△ curves for lactose and chloride are identical in character with those exhibited for variation of percentage concentration (see Figures 12 and 13), and are shown to be very strongly complementary in the early and mid-lactation periods. Residual △ variation during this period, therefore, would appear to be the controlling factor causing milk △ values to behave as they do and the character of the F.P. curves are observed to be analogous in trend as well as in degree of variation.

The same degree of constancy of △ lactose plus △ chloride is not maintained in relatively late lactation, wherein it is noted that residual △ and the △ effect of lactose plus chloride are complementary to a greater degree, with resulting stabilisation of milk △ values.

The feature of △ curve interactions, is the behaviour of residual △.

It was previously stated that the titratable acidity curves reflect to a great degree the variation within a lactation of the soluble acid phosphate fraction of milk. In Figure 8, F.P. and acidity curves were shown to be most similar in trend during early and mid-lactation. The same strong relationship holds between residual △ and acidity variation, sustained, however, throughout the complete lactation.

The soluble acid phosphates, presumably present in milk as the potassium salts, contribute, according to *Porcher* and *Chevallier* (1923), the greatest value to milk △ of all the non-lactose-chloride salt combinations, being approximately equal in degree to that contributed by citrates, non-protein N and colloidal complexes.

Based on such evidence, residual △ variation can be expected to reflect the variation of soluble acid phosphate.

Residual △ behaviour, therefore, supports and confirms the hypothesis advanced to explain the mechanism of acidity variation and the obvious lack of correlation shown between S.N.F. and acidity in the late stages of lactation.

Section V.

SEASONAL VARIATION IN THE CHEMICAL COMPOSITION OF PASTURE ASSOCIATED WITH GRAZING OF COW "X".

Results of chemical analyses conducted on pasture samples taken at specified intervals throughout the seasonal periods covered by the lactation, are presented in Table 9 and graphically in Figure 17.

TABLE 9.

Seasonal Pasture Analyses.

(Percentages expressed on dry weight basis.)

Seasonal Month	% Fat Ether Extract.	% Total Ash.	% Crude Fibre	% Crude Protein N. × 6.25	% Crude Carbohydrate (by Difference).
Graph Ref. No.	**1**	**2**	**3**	**4**	**5**
1947					
20th August	3·41	9·57	15·29	28·15	43·56
26th September	3·21	11·73	21·02	24·22	39·82
24th October	2·40	9·50	20·80	18·45	48·85
21st Nov. (A)	1·09	7·05	28·96	10·20	52·69
21st Nov. (B)	2·05	6·16	33·24	11·46	47·08
21st Nov. (C)	1·97	4·82	21·36	19·50	52·35
1948					
7th January	1·74	7·29	30·47	8·38	52·12
31st January	1·06	5·83	33·37	5·40	54·34
14th February	0·98	5·36	36·43	4·49	52·74
28th February	2·99	8·85	21·13	17·04	50·00
16th March	3·94	10·83	14·44	30·31	40·48
15th May	4·68	9·37	14·71	29·30	41·94
21st June	4·75	10·17	14·92	29·39	40·77
7th August	4·91	9·66	14·30	28·50	42·63

(A) Full cut grass.
(B) Maturing grass heads.
(C) Clover mixture.

Every endeavour was made to present a picture, based on long observation, of the cow's grazing habits prior to pasture sampling, of the composition quality of feed intake, not only from what was available but from what the animal was actually dominantly grazing from the pasture.

The "spring response" of pasture growth is illustrated in Plates I and II and the summer stubble condition in Plate III.

As compared with the highly nutritious quality of the short and relatively unavailable fresh growth arising from the winter sward (late August sample), ash, fat, and especially protein contents are observed to decline and carbohydrate and crude fibre to increase materially as pasture growth progresses.

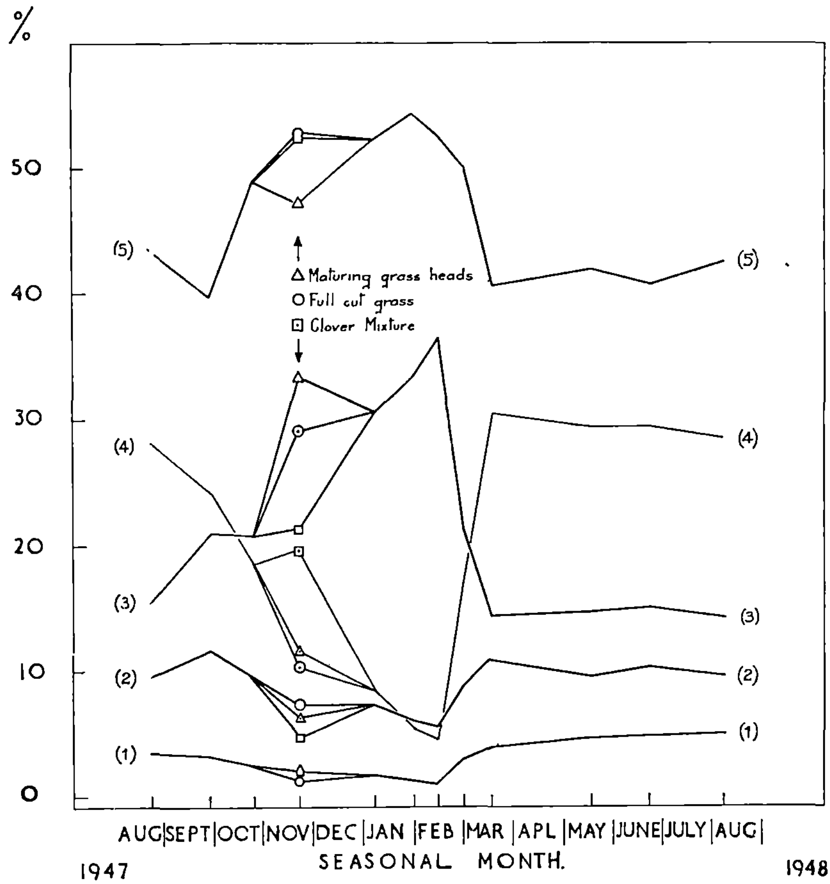

FIG. 17.—Seasonal Variation in the Chemical Composition of Pasture Samples, associated with the Food Intake of Cow "X" during the Lactation Period.
Per cent, (1) Fat (Ether Extract); (2) Ash; (3) Crude Fibre; (4) Crude Protein, (N x 6.25); (5) Crude Carbohydrate.

Selective grazing was most evident as pasture constituents commenced to mature in late November, distinct preference being shown for flowering and developing seed heads of grasses and the basal matrix of clovers in the pasture sward, such grazing habits giving to the pasture cover, a shorn, stubble appearance. (See Plate III.)

As summer progressed, a greater degree of selective grazing was observed and the pasture samples are representative of that available but not necessarily being ingested.

It is noted, however, that in late summer (February), the general chemical quality of the pasture is poorest coinciding with that period of the lactation when S.N.F. and △ values fell very rapidly.

With the advent of early autumn rains and associated heavy dews, reduced temperatures and rate of evaporation, the fresh green shoots, which appeared as a result, were heavily grazed and March samples may be regarded as non-typical of available pasture but representative of that being dominantly grazed.

Plate 1.—Pasture at 20th August, 1947.
Illustrating pasture condition associated with observed galactopoietic effect of spring growth.

Dairy stock were observed to show utter disregard to standing " summer stubble " once signs of fermentation became evident as a result of altered climatic conditions.

The chemical composition of fresh autumn growth is observed to be analogous to that of very early spring and was sustained throughout the winter season. Of importance, however, is the degree of availability, which was always very poor.

Plate 2.—Pasture at 26th September, 1947.
Illustrating pasture condition associated with observed galactopoietic effect of spring growth.

Such evidence is contrary to the findings of *Fagan* (1927) that fresh autumn growth is less nutritious than spring growth.

The greatly depressed protein values of late summer pasture are in agreement with the findings of *Fagan* and *Jones* (1924) ; *Woodman et alia* (1926, 1927) ; *Rigg* and *Askew* (1930) ; *Hudson et alia* (1933) ; *Fagan* and *Milton* (1933) ; that during dry weather the protein content of herbage falls considerably.

Plate 3.—Pasture at 14th February, 1948.

Illustrating pasture condition associated with the acute late summer decrease of S.N.F. and $\triangle$ values.

However, our results indicate strongly that the change in pasture composition is an orderly one, the direct result of a gradual alteration in those environmental factors which so strongly influence the structural development and character of plant growth.

Minimum protein, ash and fat, and maximum crude fibre and carbohydrate values were associated with the dry weather and relatively high temperatures of late summer, but such chemical quality is considered to be an expression of the end-growth condition of the pasture.

Section VI.

THE RELATION OF VARIATION IN THE THERMAL CONDITIONS OF ENVIRONMENT TO S.N.F. AND △ VALUES.

The data presented in Figure 18 is not fundamentally an expression of the effect of exposure on S.N.F. and △ variation, owing to the operation under practical dairy herd management of so many uncontrolled factors and hence no exact conclusion can be formulated relative to temperature effect, which would be applicable to the complete lactation period.

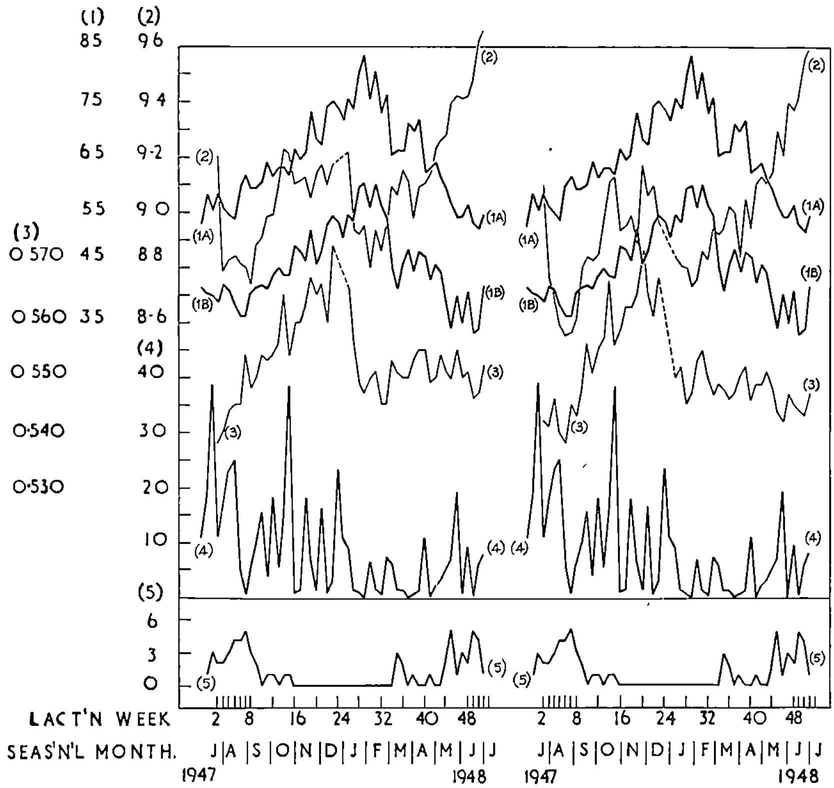

FIG. 18.—Graphs depicting the Seasonal incidence of Rainfall and Variation in the Thermal Conditions of environment associated with the lactation period of Cow "X" and relationship to S.N.F. and △ values of "MORNING" and "EVENING" Milk.

(1A) Maximum temperature °C; (1B) Minimum temperature °C; (2) Per cent S.N.F.: (3) △ °C (4) Rainfall—points; (5) Frost incidence—number per lactation week.

With the exception of (5) ordinates of graphs represent the average daily values for each week of lactation.

However, the temperature—S.N.F. and temperature—△ curve interactions are shown to be strongly complementary from early to late summer, such relationship extending to autumn with S.N.F. Such reciprocal variation cannot be regarded as due to a set of fortuitous circumstances and would appear to indicate a very positive reaction of the lactating animal to the direct changes in the environmental temperature, with resultant alteration in the physico-chemical characteristics of the milk produced.

As the chemical quality of available pasture during summer is shown in Figure 17 to be relatively stable, the data strongly indicates the rapid summer decline in S.N.F. and $\triangle$ values to be directly associated with high and rising temperatures.

It has been established, *Dice* (1935), that the dairy cow is able to withstand long periods of exposure to relatively low temperatures with little loss in production or in the efficiency of food utilization, provided they have access to shelter, adequate food and freedom from draughts, but that high temperatures have a markedly detrimental effect, *Rhoad* (1936).

The controlled effect of environmental temperature on high producing dairy cows, under psychrometric and standard diet conditions, has been studied by *Regan* and *Richardson* (1938). It was observed that with rise in temperature, milk yield, S.N.F., protein and $\triangle$ values decreased, while the pH and fat increased, the relative changes in the physico-chemical characteristics, becoming most marked and trends very definite, as the temperature rose above 80° F. At such temperature level, a pyrexial point was reached due to non-ability of the heat-regulating mechanism of the cow to maintain essential heat balance. In response to the high thermal conditions of environment, body or metabolic heat production over-balanced heat loss, body temperature rose, anorexia developed, and drastic changes in milk characteristics occurred.

Associated with the relative high temperatures of mid-late summer in this work, findings analogous to those of *Regan* and *Richardson* have been observed. In regard to the pH of milk, reference to the variation curve of inherent titratable acidity, reveals a sudden depression of values in summer, which infers a decrease in the buffering capacity of milk and hence increase in the pH and is supported by the analogous behaviour of residual $\triangle$ effect.

Their suggestion that such physico-chemical trends could best be explained on the basis of blood changes brought about to facilitate heat dissipation, may have limited application in this work. However, any direct influence of temperature is greatly masked by the operation of such factors as stage of lactation and pasture quality change.

It was previously recorded that in summer the S.N.F. and $\triangle$ values of p.m. milk significantly decreased prior to a.m. and they are shown here to exhibit ultimately an analogous degree of reciprocal variation with temperature. It is probable that, associated with daytime milk elaboration (p.m. milking), the dairy cow shows a greater degree of hyperthermy and consequently significant changes in milk composition initiated at a much earlier stage of the lactation.

Periods of significant milk composition change are noted to be constantly associated with change in trend of temperature variation and p.m. milk values constantly elevate and depress prior to a.m., irrespective of the degree of trend depression or elevation.

It is quite conceivable therefore that such an occurrence is intimately bound up with the direct and indirect influences of temperature.

Data relevant to seasonal distribution of rainfall and frost occurrence are presented in Figure 18, which, in conjunction with temperature, provide a picture of the variability of some climatic factors covering the period of lactation and therefore directly and indirectly affecting the lactating animal and pasture growth.

* * * * *

CONCLUSION.

This study reveals that milk exhibits continual changes in composition which proceeds throughout lactation in a most regulated and controlled manner.

At no stage can it be regarded as possessing a static composition. The alteration in milk quality seemingly reflects the reaction of a biological unit in a constantly changing environment.

In view of the basic relationship of blood to milk, the elaboration and secretion of a progressively changing end-product may imply variability, either in the nutritional quality of blood supplying the precursors of milk to the alveolar tissue, and/or in the intensity and efficiency of the specific biochemical metabolism within the alveolar cell influenced by regulated, internal stimuli, which vary in accordance with adaption by the dairy animal to changing seasonal conditions.

It is recognised that hormonal regulation of changes in blood composition and specific milk character elaboration are intimately associated with lactogenesis, initial galactopoiesis and the close of lactation, at which extreme periods milk shows an analogous composition.

It is also highly probable that the physico-chemical trends of mid-lactation milk are governed by hormonal processes, which dominate any direct or indirect influence of environmental stimuli.

On the other hand, the work does strongly indicate that seasonal changes in the thermal and nutritional conditions of environment, are intimately associated with osmotic disturbances in the milk.

If blood and milk are to be regarded as isotonic fluids in dynamic equilibrium on different sides of a complex system of membranes, then the osmotic disturbances noted for milk must equally apply to blood, in which case the above implications are supported.

Under the conditions of the experiment, it cannot be determined whether the primary and secondary effects of environment are directly responsible.

As for the mechanism of S.N.F. and $\triangle$ variation, it has been shown in this work, that the specific behaviours of respective protein and non-lactose-chloride or "residual" $\triangle$ values exert the greatest influence upon the character of the lactation trends observed.

S.N.F. and $\triangle$ variations, during mid-lactation conform to the progressive change previously recorded for bulk market milk, during the corresponding periods of spring and summer.

This and other relevant evidence, substantiates the contention that the stage of lactation is of paramount importance in its effect on the change of milk composition and that nutrition and environment are intimately linked with the operation of this factor.

* * * * *

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APPENDIX

TABLE A.

Weighted average daily values of physico-chemical tests and production figures obtained for five consecutive MORNING milkings taken in each week of lactation.

Lact. Week No	Wgt Milk lbs.	% T S.	% S.N.F.	% F	% Lactose.	% Cl.	△ °C.	% Acidity	Wgt. T S lbs	Wgt S N F lbs.	Wgt F lbs.
2	12·17	13·913	9·195	4·718	4·883	0·0851	0·538	0·140	1·6927	1·1187	0·5740
3	13·80	12·764	8·793	3·971	4·917	0·0902	0·540	0·129	1·6976	1·1694	0·5282
4	15·60	12·382	8·832	3·550	5·076	0·0836	0·544	0·135	1·9316	1·3778	0·5538
5	16·80	12·410	8·835	3·575	5·082	0·0795	0·545	0·133	2·0849	1·4843	0·6006
6	18·00	12·470	8·807	3·663	5·054	0·0792	0·545	0·138	2·2446	1·5853	0·6593
7	16·95	12·943	8·800	4·143	5·065	0·0780	0·554	0·158	2·1939	1·4917	0·7022
8	17·30	12·601	8·738	3·863	5·127	0·0726	0·548	0·142	2·1800	1·5116	0·6684
9	17·80	12·743	8·883	3·860	5·219	0·0722	0·550	0·142	2·2682	1·5812	0·6870
10	18·50	12·616	8·899	3·717	5·157	0·0676	0·554	0·150	2·3339	1·6463	0·6876
11	19·20	12·737	8·981	3·756	5·167	0·0694	0·553	0·148	2·4455	1·7243	0·7212
12	20·50	12·533	8·990	3·543	5·183	0·0722	0·554	0·162	2·5693	1·8430	0·7263
13	20·60	12·198	9·087	3·111	5·147	0·0724	0·556	0·163	2·5129	1·8719	0·6410
14	20·60	12·406	9·226	3·180	5·243	0·0710	0·565	0·166	2·5557	1·9005	0·6552
15	19·05	12·431	9·207	3·224	5·209	0·0735	0·554	0·156	2·3681	1·7539	0·6142
16	17·40	12·854	9·096	3·758	5·210	0·0771	0·560	0·152	2·2365	1·5827	0·6538
17	17·90	12·676	9·106	3·570	5·154	0·0744	0·560	0·152	2·2690	1·6299	0·6391
18	18·60	12·530	9·127	3·403	5·131	0·0772	0·563	0·150	2·3307	1·6977	0·6330
19	18·80	12·711	9·047	3·664	5·089	0·0776	0·568	0·154	2·3896	1·7009	0·6887
20	17·35	12·535	9·141	3·394	5·098	0·0754	0·565	0·160	2·1749	1·5860	0·5889
21	18·95	12·656	9·166	3·490	5·132	0·0748	0·567	0·164	2·3983	1·7369	0·6614
22	17·70	12·679	9·099	3·580	5·121	0·0820	0·560	0·158	2·2443	1·6106	0·6337
23	17·30	12·678	9·170	3·508	5·157	0·0784	0·574	0·168	2·1933	1·5864	0·6069
26	16·35	13·058	9·211	3·847	5·127	0·0830	0·566	0·160	2·1351	1·5060	0·6291
27	16·00	13·247	8·937	4·310	5·116	0·0838	0·556	0·148	2·1194	1·4298	0·6896
28	14·40	13·354	8·921	4·433	4·926	0·0846	0·549	0·148	1·9230	1·2846	0·6384
29	14·05	13·011	8·954	4·057	4·970	0·0863	0·547	0·148	1·8280	1·2580	0·5700
30	14·00	12·943	8·800	4·143	5·007	0·0884	0·550	0·160	1·8120	1·2320	0·5800
31	13·50	13·241	8·941	4·300	4·971	0·0969	0·551	0·155	1·7875	1·2070	0·5805

32	13·95	13·137	8·859	4·278	4·853	0·0929	0·545	0·163	1·8327	1·2359	0·5968
33	13·55	13·415	8·954	4·461	4·870	0·0857	0·545	0·154	1·8177	1·2132	0·6045
34	13·00	13·874	9·094	4·780	4·874	0·0911	0·553	0·168	1·8037	1·1822	0·6215
35	12·45	13·715	9·056	4·659	4·889	0·0853	0·551	0·160	1·7075	1·1275	0·5800
36	12·85	13·879	9·153	4·726	4·816	0·0838	0·550	0·158	1·7833	1·1761	0·6072
37	12·63	13·874	9·106	4·768	4·782	0·0874	0·550	0·160	1·7343	1·1383	0·5960
38	12·10	13·649	8·979	4·670	4·780	0·0857	0·553	0·157	1·6515	1·0864	0·5651
39	12·00	13·923	9·085	4·838	4·862	0·0878	0·555	0·165	1·6708	1·0902	0·5806
40	11·90	13·962	9·096	4·866	4·806	0·0900	0·555	0·160	1·6616	1·0825	0·5791
41	12·15	13·959	9·135	4·824	4·760	0·0864	0·549	0·160	1·6960	1·1099	0·5861
42	12·10	13·953	9·234	4·719	4·817	0·0854	0·550	0·162	1·6883	1·1173	0·5710
43	12·10	14·051	9·259	4·792	4·864	0·0871	0·554	0·158	1·7002	1·1203	0·5799
44	12·05	14·276	9·279	4·997	4·788	0·0841	0·551	0·156	1·7202	1·1181	0·6021
45	11·20	14·745	9·394	5·351	4·844	0·0818	0·550	0·148	1·6515	1·0522	0·5993
46	10·75	14·723	9·415	5·308	4·962	0·0822	0·555	0·154	1·5827	1·0121	0·5706
47	10·60	14·631	9·409	5 222	4·801	0·0834	0·550	0·152	1·5508	0·9973	0·5535
48	9·90	14·965	9·418	5·547	4·836	0·0846	0·551	0·142	1·4816	0·9324	0·5492
49	9·70	14·883	9·475	5·408	4·812	0·0847	0·546	0·139	1·4437	0·9191	0·5246
50	8·85	14·867	9·619	5·248	4·868	0·0900	0·547	0·131	1·3157	0·8513	0·4644
51	7·55	14·906	9·662	5·244	4·767	0·0975	0·552	0·141	1·1250	0·7295	0·3955
52*	9·25	15·89	9·80	6·09	4·461	0·118	0·548	0·108	1·4699	0·9066	0·5633
53*	5·75	15·65	9·72	5·93	4·040	0·147	0·545	0·093	0·8999	0·5589	0·3410

* Experimental animal a.m. milked once per diem during the 52nd and 53rd weeks of lactation.

No samples secured for analysis during the 24th and 25th lactation weeks.

TABLE B.

Weighted average daily values of physico-chemical tests and production figures obtained for five consecutive EVENING milkings taken in each week of lactation.

Lact Week No	Wgt Milk lbs.	% T S.	% S N.F.	% F	% Lactose.	% Cl.	△ °C.	% Acidity.	Wgt T.S. lbs.	Wgt S N F. lbs.	Wgt F lbs.
2	9·08	14·516	9·070	5·446	4·794	0·0880	0·542	0·140	1·3181	0·8236	0·4945
3	9·30	13·597	8·761	4·836	4·906	0·0885	0·541	0·130	1·2645	0·8148	0·4497
4	11·10	13·357	8·682	4·675	4·988	0·0819	0·546	0·132	1·4826	0·9637	0·5189
5	13·50	13·146	8·593	4·553	4·994	0·0753	0·540	0·135	1·7748	1·1601	0·6147
6	13·15	13·380	8·546	4·834	4·950	0·0782	0·538	0·135	1·7594	1·1237	0·6357
7	16·05	12·765	8·555	4·210	5·062	0·0761	0·545	0·146	2·0489	1·3731	0·6758
8	15·95	13·260	8·613	4·647	5·050	0·0724	0·543	0·140	2·1148	1·3737	0·7411
9	15·50	13·435	8·799	4·636	5·145	0·0694	0·548	0·142	2·0825	1·3639	0·7186
10	15·55	13·908	8·836	5·072	5·108	0·0655	0·556	0·148	2·1629	1·3741	0·7888
11	15·90	13·563	8·829	4·734	5·094	0·0694	0·551	0·152	2·1564	1·4037	0·7527
12	17·15	13·610	8·845	4·765	5·121	0·0723	0·555	0·160	2·3343	1·5170	0·8173
13	17·55	12·983	8·987	3·996	5·103	0·0690	0·557	0·168	2·2784	1·5772	0·7012
14	17·75	13·417	9·122	4·295	5·128	0·0685	0·568	0·164	2·3814	1·6191	0·7623
15	16·25	13·582	9·138	4·444	5·172	0·0704	0·556	0·154	2·2072	1·4850	0·7222
16	14·60	13·789	8·927	4·862	5·086	0·0768	0·559	0·148	2·0133	1·3034	0·7099
17	15·40	13·488	8·954	4·534	5·056	0·0728	0·563	0·156	2·0772	1·3790	0·6982
18	15·65	14·040	8·989	5·051	5·032	0·0738	0·563	0·144	2·1973	1·4068	0 7905
19	15·95	13·904	8·888	5·016	4·934	0·0738	0·565	0·148	2·2177	1·4176	0·8001
20	16·35	14·348	9·172	5·176	5·112	0·0742	0·573	0·152	2·3459	1·4997	0·8462
21	16·40	13·760	9·056	4·704	5·081	0·0744	0·565	0·156	2·2566	1·4852	0·7714
22	16·05	13·628	9·099	4·529	5·061	0·0800	0·561	0·160	2·1875	1·4605	0·7270
23	16·75	13·561	8·955	4·606	4·988	0·0757	0·568	0·156	2·2714	1·4999	0·7715
26	13·65	14·126	8·838	5·288	4·865	0·0797	0·550	0·146	1·9282	1·2064	0·7218
27	15·05	13·596	8·812	4·784	4·925	0·0818	0·552	0·150	2·0461	1·3262	0·7199
28	15·20	13·124	8·795	4·329	4·822	0·0852	0·545	0·150	1·9950	1·3369	0·6581
29	14·35	13·281	8·730	4·551	4·874	0·0881	0·547	0·155	1·9058	1·2528	0·6530
30	13·50	13·180	8·747	4·433	4·888	0·0897	0·553	0·153	1·7793	1·1808	0·5985
31	13·05	13·342	8·863	4·479	5·031	0·0936	0·555	0·155	1·7412	1·1566	0·5846
32	13·60	13·550	8·829	4·721	4·773	0·0938	0·550	0·165	1·8427	1·2007	0·6420
33	13·05	13·644	8·954	4 690	4·808	0·0874	0·547	0·158	1·7806	1·1685	0·6121
34	12·50	13·830	8·919	4·911	4·770	0·0895	0·549	0·158	1·7287	1·1148	0·6139

35	12·65	14·007	8·940	5·067	4·778	0·0852	0·548	0·160	1·7719	1·1309	0·6410
36	12·00	14·253	9·024	5·229	4·729	0·0832	0·546	0·160	1·7104	1·0829	0·6275
37	12·69	14·500	9·002	5·498	4·788	0·0842	0·547	0·160	1·8367	1·1403	0·6964
38	11·85	14·208	8·839	5·369	4·733	0·0850	0·550	0·160	1 6837	1·0475	0·6362
39	10·75	14·348	9·047	5·301	4·805	0·0859	0·552	0·160	1·5425	0·9726	0·5699
40	11·00	14·291	8·952	5·339	4·686	0·0892	0·546	0·157	1·5720	0·9847	0 5873
41	11·20	14·501	9·102	5·399	4·738	0·0880	0·549	0·156	1·6242	1·0195	0·6047
42	10·75	14·361	9·131	5·230	4·736	0·0877	0·549	0·154	1·5437	0·9815	0·5622
43	11·05	14·477	9·111	5·366	4·823	0·0870	0·551	0·155	1·5997	1·0068	0·5929
44	10·80	14·584	9·139	5·445	4·734	0·0842	0·548	0·152	1·5751	0·9870	0·5881
45	9·95	14·906	9·295	5·611	4·771	0·0836	0·544	0·148	1·4831	0·9248	0·5583
46	10·70	14·663	9·204	5·459	4·731	0·0815	0·542	0·148	1·5689	0·9848	0·5841
47	10·40	14·921	9·401	5·520	4·775	0·0834	0·547	0·152	1·5518	0·9777	0·5741
48	9·30	14·814	9·370	5·444	4·750	0·0848	0·545	0·150	1·3777	0·8714	0·5063
49	8·65	15·195	9·405	5·790	4·758	0·0858	0·544	0·138	1·3143	0·8135	0·5008
50	8·40	15·076	9·563	5·513	4·781	0·0901	0·543	0·142	1·2664	0·8033	0·4631
51	7·45	15·333	9·586	5·747	4·730	0·0948	0·547	0·149	1·1424	0·7142	0·4282

No samples secured for analysis during the 24th and 25th lactation weeks.

TABLE C.

Weighted average daily Total Yield, Composition Values and Production records, computed from the figures obtained for five consecutive EVENING and MORNING milkings, secured within each week of lactation.

Lact Week No.	Yield Milk lbs	% T S.	% S N F	% F.	Weight T S. lbs	Weight S.N F lbs.	Weight F. lbs.
2	21·25	14·17	9·14	5·03	3·0113	1·9426	1·0687
3	22·60	13·11	8·78	4·33	2·9621	1·9842	0·9779
4	26·70	12·79	8·77	4·02	3·4142	2·3415	1·0727
5	30·30	12·74	8·73	4·01	3·8597	2·6444	1·2153
6	31·15	12·86	8·70	4·16	4·0040	2·7090	1·2950
7	33·00	12·86	8·68	4·18	4·2428	2·8648	1·3780
8	33·25	12·92	8·68	4·24	4·2948	2·8853	1·4095
9	33·30	13·06	8·84	4·22	4·3507	2·9451	1·4056
10	34·05	13·21	8·87	4·34	4·4968	3·0204	1·4764
11	35·10	13·11	8·91	4·20	4·6019	3·1280	1·4739
12	37·65	13·02	8·92	4·10	4·9036	3·3600	1·5436
13	38·15	12·56	9·04	3·52	4·7913	3·4491	1·3422
14	38·35	12·88	9·18	3·70	4·9371	3·5196	1·4175
15	35·30	12·96	9·18	3·78	4·5753	3·2389	1·3364
16	32·00	13·28	9·02	4·26	4·2498	2·8861	1·3637
17	33·30	13·06	9·04	4·02	4·3462	3·0089	1·3373
18	34·25	13·22	9·06	4·16	4·5280	3·1045	1·4235
19	34·75	13·26	8·97	4·29	4·6073	3·1185	1·4888
20	33·70	13·42	9·16	4·26	4·5208	3·0857	1·4351
21	35·35	13·17	9·12	4·05	4·6549	3·2221	1·4328
22	33·75	13·13	9·10	4·03	4·4318	3·0711	1·3607
23	34·05	13·11	9·06	4·05	4·4647	3·0863	1·3784
26	30·00	13·54	9·04	4·50	4·0633	2·7124	1·3509
27	31·05	13·42	8·88	4·54	4·1655	2·7560	1·4095
28	29·60	13·24	8·86	4·38	3·9180	2·6215	1·2965
29	28·40	13·15	8·84	4·31	3·7338	2·5108	1·2230
30	27·50	13·06	8·77	4·29	3·5913	2·4128	1·1785
31	26·55	13·29	8·90	4·39	3·5287	2·3636	1·1651
32	27·55	13·34	8·84	4·50	3·6754	2·4366	1·2388
33	26·60	13·52	8·95	4·57	3·5983	2·3817	1·2166
34	25·50	13·85	9·01	4·84	3·5324	2·2970	1·2354
35	25·10	13·86	9·00	4·86	3·4794	2·2584	1·2210
36	24·85	14·06	9·09	4·97	3·4937	2·2590	1·2347
37	25·32	14·10	9·00	5·10	3·5710	2·2786	1·2924
38	23·95	13·93	8·91	5·02	3·3352	2·1339	1·2013
39	22·75	14·13	9·07	5·06	3·2133	2·0628	1·1505
40	22·90	14·12	9·03	5·09	3·2336	2·0672	1·1664
41	23·35	14·22	9·12	5·10	3·3202	2·1294	1·1908
42	22·85	14·15	9·19	4·96	3·2320	2·0988	1·1332
43	23·15	14·26	9·19	5·07	3·2999	2·1271	1·1728
44	22·85	14·42	9·21	5·21	3·2953	2·1051	1·1902
45	21·15	14·82	9·35	5·47	3·1346	1·9770	1·1576
46	21·45	14·69	9·31	5·38	3·1516	1·9969	1·1547
47	21·00	14·77	9·40	5·37	3·1026	1·9750	1·1276
48	19·20	14·89	9·39	5·50	2·8593	1·8038	1·0555
49	18·35	15·03	9·44	5·59	2·7580	1·7326	1·0254
50	17·25	14·97	9·59	5·38	2·5821	1·6546	0·9275
51	15·00	15·12	9·63	5·49	2·2674	1·4437	0·8237
52	9·25	15·89	9·80	6·09	1·4699	0·9066	0·5633
53	5·75	15·65	9·72	5·93	0·8999	0·5589	0·3410

No samples secured for analysis during the 24th and 25th lactation weeks.

TABLE D.

Experimental Data Relative to Mechanism of S.N.F. Variation.

Lact Week No.	EVENING MILK Weight Milk lbs	EVENING MILK % S.N.F	EVENING MILK % Lactose	EVENING MILK % Ash.	EVENING MILK % Protein (by diff.)	MORNING MILK Weight Milk lbs	MORNING MILK % S.N.F	MORNING MILK % Lactose	MORNING MILK % Ash	MORNING MILK % Protein (by diff.)	COMPOSITE SAMPLE % Casein	COMPOSITE SAMPLE % Albumin.
2		8·73	4·59	0·992	3·148		8·82	4·76	0·995	3·065	2·72	0·397
3	10·0	9·11	4·95	0·965	3·195	13·00	8·96	4·94	0·934	3·086	2·744	0·369
4	12·0	8·84	5·06	0·774	3·006	14·25	8 97	5·02	0·865	3·085	2·557	0·373
5	13·5	8·67	4·92	0·891	2·859	17·75	8·82	5·02	0·931	2·869	2·48	0·440
6	16 0	8·56	4·99	0·878	2·692	19·00	8·71	4·96	0·817	2·933	2·46	0·340
7	15·5	8·45	4·99	0·852	2·608	18·25	8·67	5·10	0·818	2·752	2·25	0·401
8	15·25	8·59	5·11	0·840	2·640	16·00	8·71	5·27	0·788	2·652	2·43	0·321
9	15 25	8·89	5·15	0·782	2·958	18·00	8·87	5·17	0·839	2·861	2·41	0·330
10	16·50	8·85	5·14	0·832	2·878	18·50	8 91	5·13	0·794	2·986	2·44	0·380
11	16·50	8·75	5·11	0·834	2·806	19·00	9·03	5·14	0·779	3·111	2·51	0·380
12	17·50	8·93	5·27	0·800	2·860	20·50	9·07	5·11	0·825	3·135	2·53	0·418
13	19·50	8·80	5·09	0·799	2·911	20·50	9·15	5·25	0·799	3·101	2·55	0·346
14	18·00	9·11	5·07	0·797	3·243	21·00	9·23	5·25	0·830	3·150	2·69	0·355
15	17·50	9·16	5·27	0·790	3·100	20·75	9·21	5·27	0·814	3·126	2·64	0·428
16	15·00	8·83	5·10	0·755	2·975	18·50	9·03	5·29	0·815	2·925	2·45	0·449
17	16 00	8·91	5·06	0·755	3·095	17·50	8·97	5·07	0·789	3·111	2·54	0·403
18	15·50	9·10	5·13	0·764	3·206	19·00	9·07	5·15	0·825	3·095	2·70	0·412
19	16·50	8·94	4·97	0·727	3·243	19·00	9·06	5·13	0·830	3·100	2·66	0·452
20	17·00	8·96	4·89	0·750	3·320	18·00	9·12	4 97	0·812	3·338	2·52	0·398
21	16·50	9·04	5·20	0·819	3·021	19·25	9·07	5·21	0·765	3·095	2·71	0·402
22	17·50	9·00	5·07	0·789	3·141	18·00	8·97	5·07	0·785	3·115	2·63	0·460
23	16 50	9·23	4·92	0·805	3·505	17·00	9·30	5·17	0·822	3·308	2·97	0·397
26	16·00	8·86	4·89	0·760	3·210	16·00	9·44	5·20	0·795	3·445	2·71	0·410
27	15·00	8·85	4·97	0·724	3·156	16 50	9·07	5·24	0·765	3·065	2·56	0·400
28	14·50	8·84	4·80	0·750	3·290	14·50	9·01	4·88	0·765	3·365	2·64	0·356
29	14·50	8·62	4·86	0·738	3·022	14·00	8·74	4·92	0·763	3·057	2·52	0·496
30	12·00	8·97	4·94	0·782	3·248	14·25	8·93	5·06	0·783	3·087	2·65	0·396
31	13·00	8·96	5·00	0·818	3·142	13·50	8·83	4·91	0·785	3·135	2·68	0·311
32	13·00	8·93	4·94	0·802	3·188	14·50	8·62	4·94	0·813	2·867	2·66	0·360

33	12·75	9·03	4·81	0·833	3·387	13·50	9·00	4·84	0·808	3·352	2·74	0·422
34	13·00	8·98	4·83	0·780	3·370	13·25	9·14	4·78	0·818	3·542	2·77	0·420
35	12·00	8·89	4·97	0·770	3·150	12·75	8·87	4·99	0·812	3·068	2·81	0·370
36	12·00	8·85	4·74	0·787	3·323	12·75	9·25	4·89	0·780	3·580	2·87	0·419
37	13·25	8·92	4·71	0·798	3·412	12·75	9·08	4·73	0·813	3·537	2·82	0·486
38	12·50	8·74				13·00	8·88					
39	10·00	9·12	4·95	0·815	3·355	12·25	9·16	5·00	0·868	3·292	2·92	0·485
40	11·00	8·95	4·63	0·802	3·518	12·25	9·08	4·80	0·823	3·457	2·75	0·434
41	11·00	9·02	4·70	0·783	3·537	12·25	9·11	4·64	0·825	3·645	2·93	0·342
42	10·00	9·07	4·81	0·793	3·467	12·00	9·26	4·84	0·802	3·618	2·89	0·423
43	10·00	9·03	4·84	0·837	3·353	12·25	9·37	4·85	0·838	3·682		
44	10·25	8·96	4·84	0·828	3·292	12·25	9·26	4·78	0·838	3·642	3·00	0·452
45	9·50	9·23	4·70	0·827	3·703	11·00	9·34	4·78	0·822	3·738	2·787	0·357
46	10·00	9·39	4·73	0·842	3·818	10·50	9·57	4·86	0·848	3·862	3·011	0·372
47	10·25	9·51	4·81	0·860	3·840	11·00	9·38	4·80	0·850	3·730	3·091	0·430
48	9·00	9·37	4·81	0·818	3·742	10·25	9·65	4·89	0·835	3·925	3·161	0·469
49	8·75	9·48	4·67	0·810	4·000	10·00	9·48	4·89	0·800	3·790	3·146	0·495
50	8·00	9·52	4·78	0·848	3·892	9·25	9·43	4·84	0·845	3·745	3·125	0·467
51	7·50	9·58	4·74	0·845	3·995	8·00	9·66	4·71	0·865	4·085	3·146	0·546
52*						11·00	9·82	4·70	0·896	4·224	3·55	0·500
53*						6·00	9·84	4·07	0·964	4·806	3·65	0·608

* Experimental animal a.m. milked once per diem during the 52nd and 53rd weeks of lactation.

No samples secured for analysis during the 24th and 25th lactation weeks.

TABLE E.

Experimental Data Relative to Mechanism of △ Variation.

Week of Lact.	MORNING MILK.				EVENING MILK			
	Lactose △	Total Chl'ides △	Residual △	Milk △	Lactose △	Total Chl'ides △	Residual △	Milk △
2	0·265	0·083	0·190	0·538	0·260	0·086	0·196	0·542
3	0·266	0·088	0·186	0·540	0·266	0·087	0·188	0·541
4	0·276	0·082	0·186	0·544	0·271	0·080	0·195	0·546
5	0·276	0·078	0·191	0·545	0·271	0·074	0·195	0·540
6	0·275	0·077	0·193	0·545	0·269	0·076	0·193	0·538
7	0·275	0·076	0·203	0·554	0·275	0·074	0·196	0·545
8	0·279	0·072	0·197	0·548	0·275	0·071	0·197	0·543
9	0·284	0·071	0·195	0·550	0·280	0·068	0·200	0·548
10	0·280	0·067	0·207	0·554	0·277	0·065	0·214	0·556
11	0·281	0·068	0·204	0·553	0·277	0·068	0·206	0·551
12	0·282	0·071	0·201	0·554	0·278	0·071	0·206	0·555
13	0·280	0·071	0·205	0·556	0·277	0·068	0·212	0·557
14	0·285	0·070	0·210	0·565	0·279	0·068	0·221	0·568
15	0·284	0·073	0·197	0·554	0·281	0·069	0·206	0·556
16	0·284	0·075	0·201	0·560	0·276	0·075	0·208	0·559
17	0·280	0·073	0·207	0·560	0·275	0·072	0·216	0·563
18	0·279	0·071	0·213	0·563	0·274	0·073	0·216	0·563
19	0·277	0·076	0·215	0·568	0·268	0·073	0·224	0·565
20	0·277	0·074	0·214	0·565	0·278	0·073	0·222	0·573
21	0·279	0·074	0·214	0·567	0·276	0·073	0·215	0·565
22	0·278	0·080	0·202	0·560	0·275	0·078	0·208	0·561
23	0·280	0·076	0·218	0·574	0·271	0·074	0·223	0·568
26	0·279	0·081	0·206	0·566	0·264	0·078	0·208	0·550
27	0·278	0·082	0·196	0·556	0·267	0·080	0·205	0·552
28	0·267	0·083	0·199	0·549	0·262	0·083	0·200	0·545
29	0·270	0·084	0·193	0·547	0·264	0·086	0·197	0·547
30	0·272	0·086	0·192	0·550	0·265	0·088	0·200	0·553
31	0·270	0·095	0·186	0·551	0·274	0·092	0·189	0·555
32	0·263	0·091	0·191	0·545	0·259	0·092	0·199	0·550
33	0·264	0·084	0·197	0·545	0·261	0·085	0·201	0·547
34	0·264	0·089	0·200	0·553	0·259	0·088	0·202	0·549
35	0·265	0·083	0·203	0·551	0·259	0·083	0·206	0·548
36	0·261	0·082	0·207	0·550	0·256	0·081	0·209	0·546
37	0·259	0·085	0·206	0·550	0·260	0·082	0·205	0·547
38	0·259	0·084	0·210	0·553	0·256	0·083	0·211	0·550
39	0·264	0·086	0·205	0·555	0·261	0·084	0·207	0·552
40	0·261	0·088	0·206	0·555	0·255	0·087	0·204	0·546
41	0·258	0·084	0·207	0·549	0·256	0·086	0·207	0·549
42	0·261	0·083	0·206	0·550	0·256	0·086	0·207	0·549
43	0·264	0·085	0·205	0·554	0·262	0·085	0·204	0·551
44	0·260	0·082	0·209	0·551	0·256	0·082	0·210	0·548
45	0·263	0·080	0·207	0·550	0·259	0·082	0·203	0·544
46	0·269	0·080	0·206	0·555	0·256	0·080	0·206	0·542
47	0·261	0·081	0·208	0·550	0·259	0·081	0·207	0·547
48	0·262	0·083	0·206	0·551	0·258	0·083	0·204	0·545
49	0·261	0·083	0·202	0·546	0·258	0·084	0·202	0·544
50	0·264	0·088	0·195	0·547	0·259	0·088	0·196	0·543
51	0·258	0·096	0·198	0·552	0·256	0·093	0·198	0·547
52	0·241	0·115	0·192	0·548				
53	0·217	0·142	0·186	0·545				

TABLE F.

WEATHER INFORMATION.

Average Daily Values of Temperature (maximum and minimum), Pressure, Rainfall, and number of Frosts associated with each week of Lactation. Period 1.7.47 to 31.7.48.

Week of Lactation	Maximum Temperature °F	Minimum Temperature °F.	Number of Frosts	Rainfall—Points	Pressure M S L inches 1500 hours
1	55·2	39·8	3	39·0	29·59
2	58·4	38·9	2	10·9	29·92
3	55·8	41·8	2	17·6	30·00
4	54·7	40·8	3	22·9	29·41
5	53·6	38·1	4	25·0	29·62
6	59·7	36·0	4	5·4	29·94
7	61·6	36·1	5	0·6	29·90
8	59·1	40·2	3	5·9	29·78
9	59·2	41·1	2	9·9	29·81
10	60·0	41·4		15·6	29·75
11	64·2	41·1	1	3·9	30·09
12	61·1	43·4	1	18·1	29·70
13	63·0	44·9		5·7	29·82
14	62·9	43·6	1	15·9	29·87
15	61·6	43·4	1	38·6	29·64
16	66·5	49·0		0·9	30·02
17	64·5	48·4		1·1	29·58
18	65·5	46·4		18·0	29·84
19	73·0	51·6		6·1	30·04
20	68·0	45·5		1·4	29·92
21	67·1	48·3		16·4	29·75
22	74·0	52·8		0·7	30·04
23	74·9	54·4		3·1	29·81
24	73·8	53·3		23·4	29·55
25	71·4	50·4		11·0	29·74
26	75·4	54·5		8·9	29·98
27	73·8	53·0		1·6	30·11
28	80·6	59·4		1·1	29·93
29	83·2	60·2			29·95
30	75·3	55·9		6·6	29·86
31	80·2	60·2		1·6	29·96
32	73·0	56·4		0·6	29·79
33	76·2	54·1		7·4	29·70
34	65·4	45·4		6·0	29·39
35	66·2	41·0	3	1·4	29·85
36	65·7	45·8	2	1·4	29·95
37	70·9	48·5			29·99
38	69·4	44·3	1	0·3	29·96
39	71·8	47·5		1·3	30·09
40	62·1	46·9		11·0	29·86
41	62·9	42·6	1	0·1	29·83
42	63·9	45·6		2·0	30·30
43	61·1	44·4		2·9	29·81
44	59·0	38·5	2	5·1	29·95
45	56·4	33·9	5	7·1	29·84
46	53·9	39·9	1	19·4	29·60
47	54·1	34·9	3	0·9	30·12
48	56·7	40·8	2	9·7	30·24
49	52·9	33·0	5	0·3	30·27
50	51·7	33·7	4	6·0	29·94
51	54·6	41·5	1	8·1	29·81
52	51·8	37·7	3	18·0	29·66
53	53·6	35·3	5	4·7	30·24

DERIVATION OF EXPRESSION i $= 1 + \gamma$ *UTILISED FOR CORRECTING NORMAL* $\triangle$ *VALUES OF STRONG ELECTROLYTES, CALCULATED FROM FORMULA*

$$\triangle = K.\frac{n}{W}$$

Normal $\triangle$ values are non-applicable to salts and strong electrolytes, which, when dissolved in water, give solutions having an abnormally high osmotic pressure and an abnormally low F.P. and the greater degree of abnormality is evident with increase in dilution.

As the osmotic pressure of dilute solutions is proportional to the concentration or inversely proportional to the volume, in which a given amount of substance is dissolved, and since also the pressure is proportional to the absolute temperature, according to van't Hoff, the osmotic pressure of a solution can be represented by the expression P.V. = (i R) T.; (i R) being a constant characteristic of the dissolved substance. The van't Hoff coefficient "i" for a normally behaving substance like sugar, which in dilute solution obeys the simple van't Hoff-Avogadro law P.V. = R.T., is equal to unity. But for weak and strong electrolytes it is found to be greater than unity, that is, the osmotic pressure and $\triangle$ values are greater for electrolytes compared with equimolecular solutions of non-electrolytes. The van't Hoff coefficient, therefore, represents the ratio of the observed osmotic pressure or $\triangle$ to the normal or—

$$i = \frac{\text{P observed}}{\text{P normal}} = \frac{\triangle\text{ observed}}{\triangle\text{ normal}}$$

and increases with dilution.

According to the theory of Arrhenius, the equivalent conductivity of an electrolytic solution is a measure of the degree of dissociation of the dissolved electrolyte, which is a conductivity ratio of the equivalent conductivity when dissociation is complete or when the degree of ionisation is unity, to the equivalent conductivity at a dilution of 1 gram-equivalent in "ν" litres and represented by

$$\alpha = \frac{\lambda_\nu}{\lambda_\infty}$$

If one gram molecule of a binary electrolyte like NaCl be dissolved in 1000 g. H_2O and if the fraction α of the molecules is ionised in solution, there will be $(1 - \alpha)$ gram molecule of non-ionised electrolyte and 2α gram molecule of ions; or $(1 - \alpha) + 2\alpha = 1 + \alpha$ gram molecules of solute. The observed $\triangle$ will therefore be greater than the theoretical or normal $\triangle$ (on the assumption of no dissociation) in the ratio of $1 + \alpha : 1$.

$$\text{Therefore } \frac{\triangle\text{ observed}}{\triangle\text{ normal}} = i = \frac{1 + \alpha}{1} \text{ or } i = 1 + \alpha$$

α values obtained from osmotic and conductivity measurements generally show approximate agreement but *Findlay* (1941) states that while such results apparently support in a qualitative manner at least, the hypothesis of Arrhenius of a dissociation equibilibrium between non-ionised molecules, and free and independent ions, they are illusory, for, as can be shown on thermodynamic grounds, the inter-ionic forces which, according to modern theory influence the electrical conductivity, will also affect the osmotic properties.

Quantitatively, the hypothesis is justified in the case of weak electrolytes but non-applicable to salts and strong electrolytes like those of NaCl and KCl under discussion. In the former case α or the Arrhenius coefficient may be taken as representing the degree of dissociation of the electrolyte in solution and hence the expression $1 + \alpha$ taken for the van't Hoff coefficient in calculating the observed from the normal $\triangle$. With strong electrolytes, α cannot be regarded as representing the degree of ionisation of the electrolyte and therefore the effective concentration of an ion will not be represented by $\alpha.c$ where "c" is the concentration of the electrolyte in gram molecules per 1000 g. H_2O.

The concept of degree of dissociation has therefore been replaced by the concept of "mean ion activity" due to *Lewis* (1901: 1907). The ratio of mean ion activity to the molality $\frac{a\pm}{m}$ is termed the "activity coefficient" and represented by γ. Hence $a\pm = \gamma.c$, an expression which is preferable to $\alpha.c$ in the case of a strong electrolyte, when determining the effective concentration of an ion.

Values of α are in all cases greater than the values of γ and the value differences intensify with increased concentration of solute.

Thus the value of the van't Hoff coefficient has been represented in Table VII. by the expression $i = 1 + \gamma$ and not $1 + \alpha$ and the observed or corrected $\triangle$ values for NaCl: KCl, and Cl determined from the expression ($\triangle$ normal $\times$ $(1 + \gamma)$).

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